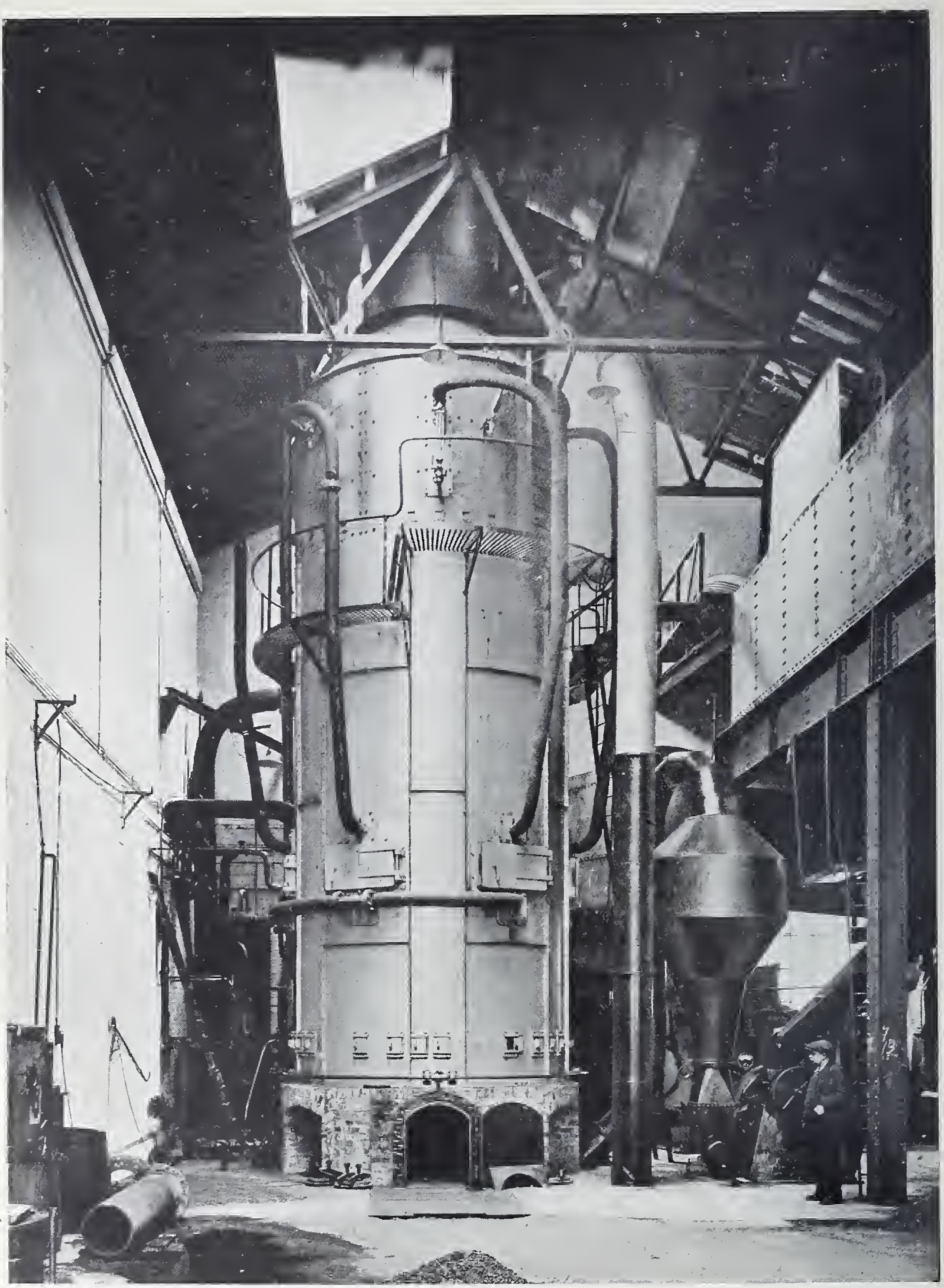
THE RECONSTRUCTIVE TECHNICAL SERIES

General Editor: G. W. DE TUNZELMAN

PULVERISED FUEL, COLLOIDAL FUEL, FUEL ECONOMY, AND SMOKELESS COMBUSTION



THE BETTINGTON BOILER.

Industrial progress in the application of pulverised fuel to steam boilers and furnaces has been influenced by the work of Claude Bettington.

Fraser and Chalmers, Ltd.] [*The General Electric Co., Ltd.*

Frontispiece.

PULVERISED FUEL, COLLOIDAL FUEL, FUEL ECONOMY, AND SMOKELESS COMBUSTION

BY

LEONARD C. HARVEY

M.I. & S.Inst., M.Inst.Met.

Author of the Fuel Research Board's Special Report No. 1, entitled "Pulverised Coal Systems in America," published for the British Government by His Majesty's Stationery Office.

New York

THE MACMILLAN COMPANY

1924

MADE AND PRINTED IN GREAT BRITAIN.
RICHARD CLAY & SONS, LIMITED,
PRINTERS, BUNGAY, SUFFOLK.

DEDICATION

THIS BOOK, CONCEIVED IN
THE SAD YEARS OF WAR, 1914–1918,
IS DEDICATED TO ALL THOSE NOBLE PATRIOTS
WHO, FIGHTING, DIED THAT OTHERS
MIGHT LIVE

PREFACE

It is no part of the object of this book to give a complete history of the early attempts to use fuel in pulverised form, if only for the reason that such a history would have small present-day importance. There are many articles, papers, and technical societies' publications giving this information, and those who desire to make a study of the art from its inception may do so by reference thereto.

Brief extracts may, however, be permitted from particulars chronicled by Bryan Donkin in a paper read by him on June 5th, 1896, before the Institute of Mining Engineers, wherein he states that the earliest attempts to burn powdered fuel in England were probably made by Crampton between 1868 and 1873, the fuel used being pulverised so that it would pass a 30-mesh sieve in particles of, say, $\frac{1}{50}$ in. The results of Crampton's research work were published in the *Proceedings of The Iron & Steel Institute* in 1873.

Data referring to a series of twenty-one boiler experiments carried out by Donkin on the Lancashire or double internal fire tube type of boiler can be found in the issue of *Engineering*, dated September 20th, 1895; Donkin used the German Wegener system with which sacks each containing about 60 lb. of powdered coal were emptied into a conical hopper. He thus describes the fuel feed action, etc. :—

" The powdered coal gradually falls out of the sacks, as required, into the hopper, and then on to a sieve about $5\frac{1}{2}$ in. in diameter, with small openings in it. The powdered coal would not go through this sieve with certainty without continual tapping, and this is done in the following way :—Immediately beneath the hopper, and level with the boiler-house floor, is an air-pipe about 20 in. in diameter, through which nearly all the air for combustion is admitted. As it enters, it is made to pass through the blades of an air-wheel or turbine, and this passage of the air causes the latter to revolve. On the axis of this air-wheel is a little knocker, which taps the sieve from 150 to 250 times per minute, causing the powdered coal to descend vertically through the sieve, meeting the air for combustion as it ascends vertically. In this way the powdered coal and air for proper combustion get thoroughly mixed, and pass on into the boiler-flue, each particle of coal being surrounded by air. The stoking simply consists of putting the sacks of powdered coal, from time to time, into the top of the hopper, and seeing that the right amount of air is entering for combustion. If there be not sufficient air for proper combustion entering through the main opening, as seen by a little smoke, there are two other smaller pipes where additional air can be admitted, each kind of coal requiring a somewhat different amount. The only object of the air-wheel revolving, from 50 to 80 revolutions per minute, is to shake the sieve and cause the powdered fuel to go into the furnace in the quantity desired. When more steam is required a greater knock is given to

the sieve, and more powdered coal is burnt; when less is needed a less shake is necessary. An adjustment is provided to regulate the amount of coal entering, which is done by turning with two fingers the $\frac{1}{2}$-in. screw. The duty of the attendant is to put the sacks of powdered coal into the hopper, and he ascends a short ladder to do this, or a conveyor can be used. One man can, therefore, attend to several boilers. The ignition of the powdered coal seems to take place immediately on its arrival in the hot firebrick chamber, and about 1 ft. from the boiler front."

This description is sufficiently indicative of the more or less crude design and constructive purpose of the equipment available at that date. Other systems, such as the Swartzkopff, Friedeberg, Ruhl, and de Camp systems, vary only in methods adopted for introducing the fuel into the air blast, or furnace, in improved fashion as claimed by the inventors. Full descriptions of these early types of equipment have lost value at the present day, and the good work of these engineers and of many other pioneers must of necessity be omitted.

In order to indicate the arrangement of the apparatus mentioned in Donkin's paper, permission has been obtained from the Federated Institution of Mining Engineers to reproduce the folding plate facing this page, showing the five systems mentioned by him.

That anything but imperfect firing results could have then been obtained was not so much the fault of the apparatus used for firing the furnaces as of the defective pulverisation of the fuel, and the failure to realise the necessity for a fine and uniform product. In the bulk supply there must have been much coarsely ground fuel, for even in a sample of the finest powder there is considerable variance in the size of the particles. A micrograph of the powdered coal used by Donkin is reproduced at p. 6.

The improvements effected in methods, machinery, and equipment in connection with pulverised coal since the year 1896 have been perhaps as great as those which have taken place in connection with the motor car, although the former are not so evident to the man in the street. There is now such a choice of machinery, or grouped apparatus known as "systems," that it is quite impossible to give space to the numerous mills, dryers, and other items of plant of competitive makes in the sections devoted to the brief descriptions of standard mill-house plant and equipment. Full description of many of the big installations in America and elsewhere can be read in the technical journals mentioned in the Bibliography. Representative types only of machines and apparatus are referred to in this book, and the author regrets that space alone has prevented the inclusion of many other recognised designs of standard equipment which may even be superior to the plant items he has selected for demonstration.

The author is a strong advocate of the practice of distributing the pulverised fuel, as soon as produced, to supply bins at the points at which the fuel is to be subsequently burned. So strongly is he convinced that this is the soundest practice that readers might be justified in thinking that he can see no good points in the mixing of pulverised fuel with air and distributing the fuel so mixed through trunk

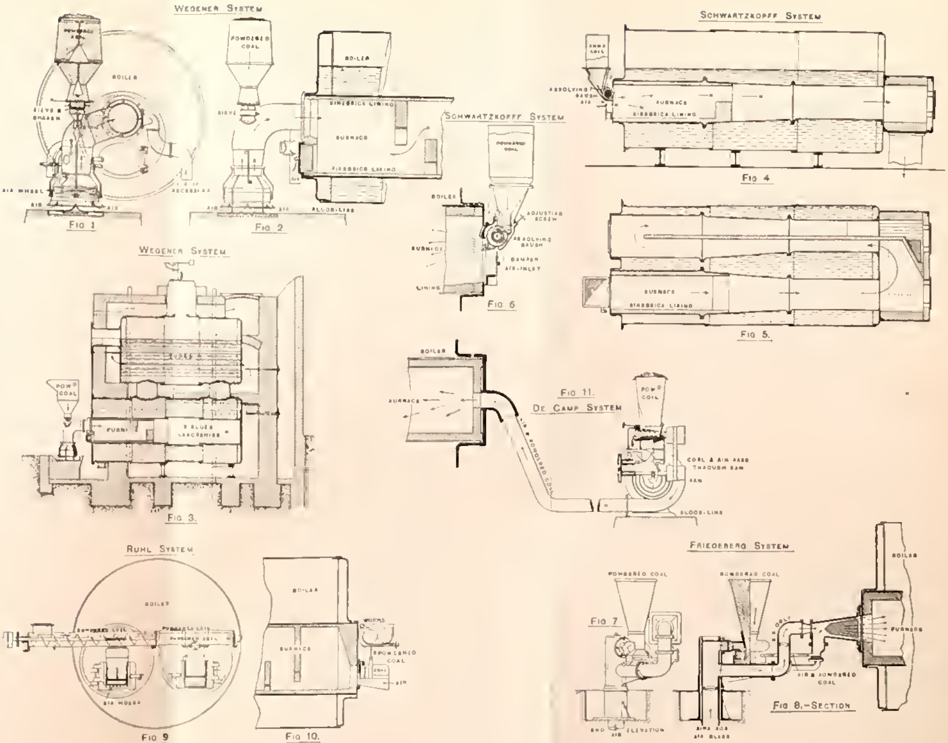


PLATE A.—EARLY TYPES OF PULVERISED COAL FIRING APPARATUS.

The Federated Institution of Mining Engineers Transactions, 1895–6. *From Bryan Donkin's Paper on "Powdered Coal for Firing Steam Boilers."*

[*To face p.* viii

mains to the furnaces. This is not so. To Holbeck, who first introduced this method of distribution, is due much of the credit for the progress subsequently made in the use of pulverised fuel.

If the air-and-fuel mixture method had been confined to its natural application to groups of small furnaces, this demonstration would have been sufficiently convincing. Its extension to the distribution of fuel in bulk has, in the author's opinion, been a mistake, since it has necessitated the introduction of elaborate devices, albeit of excellent design, and upon which much technical thought has been expended, in order to render possible the automatie regulation of fuel and air, and to maintain the required or desired velocity and density of mixture.

Because of the author's strong conviction that fuel should be distributed to subsidiary supply bins, and for no other reason, the air-and-fuel mixture system as a means of supply has not been extensively reviewed in this book. In America, up to the past few years, air-and-fuel mixture plants were more numerous than perhaps all other systems combined, but the actual distribution of fuel in air has been superseded at many such plants by other methods.

It is not suggested that the use of pulverised fuel is destined to supersede the treatment and burning of solid fuel or its constituents in ways now adopted under varying circumstances. Pulverised coal has, however, already found a wide sphere of useful applications. Its utility is purely supplemental to known and established practice, by which the heat content of fuel can be best transformed into work of equal value. For instance, it is not claimed that the use of pulverised coal will in any way supersede that of producer gas for many purposes, and in particular for use in connection with open-hearth steel melting, unless for this purpose furnaces ean be fitted with removable slag bogies, dust-settling chambers, and with special open chequer work. Given the requisite conditions, as regards design of furnaces and quality of fuel, pulverised coal may then show an economy over producer gas. There are so many instances where pulverised fuel can be applied with unquestionable advantage, that there is no need to run the risk of partial or complete failure by attempting too much. There is ample room in the many industrial processes for all known methods of heating, and pulverised coal will play a useful part in reducing both coal consumption and overall operating costs, when due consideration is given to the accumulated knowledge now available on this subject.

In the report issued by the British Nitrogen Products Committee, reference is made to the difficulty suggested in the disposal of by-product coke. It is hoped that pulverised coal systems will greatly assist in the removal of this difficulty. With low-temperature carbonising systems, there can be produced a relatively soft by-product coke containing an appreciable quantity of volatile constituents. This fuel can be readily pulverised and burned in furnaces or under boilers.

A patent has been issued in Great Britain to cover the use of low-temperature coke in this manner. How such a patent can be upheld remains to be seen, for neither the patentees nor the author are the first to recommend the use of by-product coke in this way.

Throughout this book, the author claims the privilege of presenting to readers numerous extracts from the writings of engineers and scientists of many nationalities, the recorded results of practical work by experts in the art of producing and applying pulverised coal. Opinions of his own, except upon broad principles, have not been unnecessarily obtruded, for these would not carry so great a weight of conviction as the conclusions arrived at by men who have devoted many years of their lives to the investigation of these subjects.

In a measure, this book is due to a suggestion by "Imperial," in the *Electrical Review* of Dec. 24th, 1920, that the information contained in the author's Fuel Research Board Report and in his Iron and Steel Institute paper should be incorporated in one volume. By the kindness of the publishers, this is now made possible, and the opportunity has been taken to incorporate much of the additional data which the author has been able to collect. Had it not been for the Great War, the author might never have set out upon a quest to America to report upon methods of fuel economy in that country, and but for the necessity at that time to find means for making the most of supplies of solid fuel in Great Britain, he would never have realised the unstinted assistance given him by so many American engineers. The support of America in all such matters of urgency as then existed must never be forgotten, and the author, desiring that his views of 1918 should be recorded anew in this book, takes leave to reproduce a passage from his letter in the *Times Engineering Supplement* of April 1920, wherein he endeavoured to express his appreciation of the wonderful spirit of co-operation which he everywhere found in the United States.

"The old prejudices were entirely swept away by the close of 1918, a result mainly brought about by the missionary efforts of British officers and engineers sent to the States in connection with war propaganda. Not one of those gentlemen can have anything but a lifelong feeling of gratitude and admiration for the whole-hearted hospitality so generously extended to them by Americans (not America in the political sense), and I for one can never forget this experience."

Had it not been for the energy and perseverance of the many American engineers who have devoted their life's work to the cause of pulverised coal, it would not have become standard practice to-day to arrange the immense boilers at the great Power Stations in America, France, Japan and elsewhere for pulverised coal-firing. At the present day, however, it is possible to refer to many such boiler installations regularly and continuously running at normal maker's rating, with a reserve of steaming capacity of 100% and even 200% for peak load periods.

Some of the Power-House plants provided or now being equipped with boilers of very considerable size, are :—

Milwaukee Electric Railway & Light Co., U.S.A., boilers of 13,080 and 17,500 sq. ft. of heating surface.

Ford Motor Co., U.S.A., 13,500 and 26,470 sq. ft.

Western Pennsylvania Power Co., U.S.A., 15,320 sq. ft.

Union Electric Co., U.S.A., 17,800 sq. ft.
Cleveland Electric Illuminating Co., U.S.A., 30,600 sq. ft.
Société Anonyme Union d'Électricité de Vitry, France, 16,678 sq. ft.
Nippon Electric Co., Japan, 10,080 sq. ft.
Denver Gas & Electric Co., U.S.A., 14,400 sq. ft.
Duguesne Light Co., U.S.A., 26,500 sq. ft.
Metropolitan Edison Co., U.S.A., 32,600 sq. ft.

Once again, then, the author records his thanks for past and present assistance given him in the form of information on pulverised coal systems, machinery and applications, and amongst others to the following pioneers of American pulverised coal systems: A. Holbeck (Bonnot System); W. S. Quigley (Quigley System); J. E. Muhfeld (Lopulco System); A. Pruden (Pruden System); A. J. Grindle (Grindle System); E. Covert (Covert System), whose early death was hastened by his ardent work; C. H. Bergman; E. H. Stroud; and in particular to Col. J. W. Fuller (Fuller System), who has so consistently fathered the cause of pulverised coal from its earlier stages, and has, through the Fuller Lehigh Co. of America, given to the world much of the data and practical information now available on this subject.

To a great extent the information contained herein has also been culled from original literature, or has been given or supplied to the author by such well-known workers in the world of pulverised fuel applications, as :—

Arrowood; John Anderson; Barnhurst; Bender; Browne; Bettington; Blizard; Blyth; Benner; Buell; Buttner; Caraeristi; Coutant; Cavers; Collins; Coffin; Donkin; Dick; Fitch; Carl Flodin; Gadd; Garred; Harrison; Herington; Helbig; Harrington; Jacobi; Alonzo Kinyon; Kimber; Kreisinger; Knowles; Longenecker; Lord; Mathewson; Dr. Munzinger; Maddocks; Polyssius; Rau; J. G. Robinson; Renkin; Reichenbach; Savage; Sohm; Scheffler; Snyder; Seymour; Santmeyer; Schulte; Shadgen; Sinnatt; Slater; Tracey; Townsend; Vail; Verdinne; Wood; Wilcox; Wotherspoon; Weisse; Welles; Dr. Wangemann.

It is to these pioneers of recent progress, chiefly in America, that the author is indebted even for such right as he may possess to a place amongst the writers upon such an engrossing subject as the use of solid fuel in pulverised form.

L. C. H.

January, 1924.

CONTENTS

CHAPTER VII

CHAPTER VIII

CHAPTER IX

CHAPTER X

CHAPTER XI

CHAPTER XII

LIST OF ILLUSTRATIONS

PULVERISED FUEL, COLLOIDAL FUEL, FUEL ECONOMY, AND SMOKELESS COMBUSTION

CHAPTER I

INTRODUCTION

What Pulverised Coal is—Reliability of Pulverised Fuel Firing—Conservation of Fuel—Past and Present-day Practice Contrasted—Progress in America and Elsewhere—Self-Contained Units—General Conclusions—Efficiency Engineers and Everyday Losses in Fuel Burning.

What is Pulverised Coal? The answer is, any carbonaceous fuel, be it high-grade anthracite or bituminous coal, slack and smalls, dust and pit waste, lignites, peats and brown coals (passed through a preliminary crusher if necessary), the moisture content of the fuel having been reduced to from 1% to 5%, according to the nature of the fuel to be pulverised, and which subsequently has been ground to an extremely fine powder in special mills. By this means a lump of coal of 1 cubic inch, having 6 square inches of surface for exposure on burning, may be reduced to upwards of 50,000,000 small particles, collectively presenting, say, 2000 square inches of oxidisable surface.

Misconception has arisen as to the extension of the oxidisable surface produced by pulverisation. Some writers have maintained that the number of small particles produced from 1 cubic inch of coal is in the neighbourhood of 200,000,000. But, in fact, no one can tell the approximate number owing to the mass of minute particles of smaller size than the openings in a testing sieve of 200 mesh, *i. e.* 40,000 holes per square inch.

It is sufficient as an illustration of the greatly increased oxidisable surface exposed by pulverised fuel if we consider the matter as follows :—

The average size of the openings in a 200-mesh screen is about ·0029 inch square. So, dividing 1 inch by ·0029, we get 345, which is the number of particles that together make up 1 inch; and 345^3, or 41,063,625, is the number of particles, each ·0029 inch cube, contained in 1 cubic inch of solid coal. An allowance for smaller minute particles must be made, but there is no means of measuring its extent. Surface exposure thus works out as follows :—

One cubic inch of coal exposes 6 square inches of surface. A ·0029 inch particle, assuming it to be a perfect cube, which, of course, is not the case, exposes $\cdot 0029 \times \cdot 0029 \times 6 = \cdot 005046$ square inch, and therefore $41{,}063{,}625 \times \cdot 005046 =$ 2072·705 square inches is the exposed oxidisable surface of 1 cubic inch of pulverised coal, and this is, approximately, 345 times the surface exposed by 1 solid cubic inch of coal.

B

The coal powder is blown into the furnace by a soft air blast; ignition and complete combustion take place instantaneously, a maximum flame temperature is developed, and there can be no loss of thermal value, or unconsumed carbon, under such conditions of combustion. With complete control of fuel feed and air supply, as when burning gas or oil, combustion must be perfect.

The beneficial effect of using coal in powdered form has been stated concisely by Joseph Harrington (American Society of Mechanical Engineers, October, 1916) thus :—

"In the producer there is a succession of losses which reduce the available heat in the gas to a considerable extent, and in the mechanical stoker there are unavoidable losses due to various forms of incomplete combustion. Only in the case of powdered coal is the actual solid fuel both gasified and completely consumed directly within the chamber to be heated. With perfect pulverisation the entire mass is burned in suspension, and, in actual practice, but a small fraction of 1 % is actually lost in the flue dust or slag pan.

"On account of the fuel being conveyed into the furnace by the very air which is afterwards to be used in its combustion, and on account of the diffusing of the coal throughout the air in a cloud-like formation, there is a possibility of a mixture which can be secured by no other means. Each particle of coal is surrounded by a particle of air, and on account of the extreme fineness of the particles practically instantaneous oxidisation occurs. The result is efficient combustion, and we have to deal only with the effects of the high temperature thereby obtained."

Higher temperatures than are possible with any other fuel can be maintained in powdered coal-fired melting furnaces, because the quantity of excess air is low, say, 20 %, whereas with stoker and hand firing the excess of air may range from 50 to 200 %, and even reach 300 %. It therefore follows that with powdered coal firing the products of combustion will be appreciably less than with the usual methods, and, consequently, the highly heated gases will remain in the furnaces for a longer period. The heat transference with pulverised fuel firing must, therefore, be much more complete than is the case with larger volumes of relatively cool gases which result from hand firing, or even stoker firing.

Reliability of Pulverised Fuel Firing.

The use of coal in its natural form should be curtailed to the utmost extent possible, for there is not only very considerable waste of fuel under the usual conditions of burning the coal, but the valuable constituents of coal are not put to the best commercial use by combustion in a furnace. Until such time as the power of nature in other forms, *e.g.* the immense stores of energy in waterfalls and the tides of the sea, is harnessed for distribution as motive and heating power throughout the world, recourse must be made to the burning of carbon for the production of heat. Electricity will be available in course of time from these hitherto little used or untapped sources, but until this becomes an accomplished

fact, the large Power Stations that will become essential for the needs of industry must be erected at the coal-fields.

Pending the general supply of electricity in unlimited quantity and at a cost much reduced below that of to-day, solid fuel, perhaps for many years to come, must still be burned in works; for domestic use; for firing railway locomotives; and for the hundred and one other human requirements. It behoves all users, therefore, to adopt the most economical methods known to practical science in order to conserve the world supplies of coal, and one such method is the firing of fuel in pulverised form.

As an argument against the use of pulverised coal for national services, *e. g.* for firing locomotive boilers, it is contended that the risk of stoppage of traffic on a railway cannot be entertained, and that as pulverised coal firing directly introduces such a risk, it must on that account be ruled out of consideration. But this risk is by no means so great as that attaching to failure of electric current, for failure of current may bring the whole system to a standstill.

Pulverised fuel stations as now designed work for twenty-four hours day in and day out without stoppage, and the flexibility of the essential items of the production plant is far greater than that appertaining to a generating station for the supply of electricity. Furthermore, each locomotive carries its own complement of motive power—fuel, which is not the case with electric locomotives, or railway trains running upon the multiple motor system.

The preparation and burning of pulverised coal are not new engineering subjects; engineers have considered them, tried out experiments and made failures periodically for the past fifty, or, it may be, one hundred, years. From time to time many special types of plant have been constructed in order to circumvent certain troublesome difficulties which seemed to be inseparable from pulverised coal practice. American engineers have solved most of these difficulties, and it is now possible successfully to use practically all grades and classes of solid carbonaceous fuels in this manner.

Pulverised coal has reached the level of a separate engineering project, and, so rapid has been its progress during the past few years, that it can safely be said that from now onwards the supply of fuel in this form to users from central depots; its application to metallurgical furnaces, stationary boilers, and locomotives; and its introduction on board certain classes of ships, is going to enter very forcibly into questions concerning industrial production and transport.

Conservation of Fuel.

The necessity for economy in fuel consumption is a matter that becomes of ever increasing importance in every country of the world. Certain advice given by the United States Bureau of Mines to fuel users is to the point. The last paragraph of a technical paper recently issued reads :—

"The time has passed for ever when efficiency in the use of fuel can be regarded as a matter of choice. You must either save more fuel, which you can do easily, or you must continue to lose more money, which you will do inevitably and

needlessly. You cannot pick or choose between these alternatives; you must take one or the other of these ways, for there is no middle course."

Much has recently been talked about fuel economy, but little if anything has been done to effect any material reduction in coal consumption. And yet, apart from the large quantities of coal used for domestic requirements, for naval and marine purposes, and in certain industries to which pulverised coal cannot yet be successfully applied, it is not unreasonable to suggest that 50 % of fuel now used for most purposes in industry could be saved by studying scientific economy.

From the standpoint of combustion efficiency, there is no method of burning solid fuel to surpass that of pulverisation and applying it in this form; for, leaving out of account any question of the recovery of by-products, it is known that a combustion efficiency of nearly 100 % can be obtained. Moreover, definite figures are available for economies effected by the use of pulverised fuel, such as 60 % reduction over hand-fired puddling furnaces; 40 % reduction on railway locomotives; and the 25 % economy usually recorded for metallurgical furnaces. The burning of 18,000,000 tons of pulverised coal per annum, and the erection of some 200 coal pulverising plants of daily capacities from, say, 20 to 1200 tons, in America, sufficiently confirm the profitable results to be obtained by the system.

It has been the natural consequence of the easy winning of coal at low cost, that in the past, one may say, the very cream of the coal seams has been distributed throughout the various sales markets, while, to a great extent, the inferior coal has been wasted on the mine dumps. It is in connection with the national conservation and economical use of coal that the author would specially recommend readers to give careful study to the use of fuel in pulverised form.

The carbonisation of high-class coals and the recovery of by-products are the acknowledged lines of essential development, but pulverisation of high-class coal, as well as low-grade, poor value, and residue small coal, and the burning of such in powdered form, or in colloidal combination with oil, bid fair to become methods, not only of national, but also of world importance. In this way, greatly increased efficiency can be obtained with consequent reduced consumption of expensive fuels; and carbonaceous deposits, up to now considered useless, can be utilised and applied as readily as oil. Thus will anthracite culm or washings, bituminous smalls, sub-bituminous and brown coals, lignites, and peats augment the world supply of heat-producing substances.

That this may be so is foreshadowed by the wonderful developments that have taken place during the past few years, developments which may well mean, for the outlying countries of the globe, the substitution of local inferior fuel for immense quantities of imported high-grade and costly coal; the reduction of operating expenses of colonial and foreign railway systems; and no doubt, in time, of steamship lines as well.

Furthermore, the cost of producing chemicals, copper, iron, steel, and other metals should be greatly reduced, and the opening up of new fields where at present fuel of a suitable nature is thought to be unavailable becomes possible.

Abolition of hand firing must mean the employment of labour to a far greater

extent upon skilled work, the discontinuance of unremunerative manual operations, and the betterment of working conditions. No nation that neglects to develop the scientific use of fuel and its constituents to the best advantage of industrial production can, in the future, hope to be able to compete with its more enterprising and better advised neighbours.

In view of the many and varied valuable by-products derivable from coal, which can be reclaimed only by means of distillation, it might be maintained that legislation should prohibit consumption of any coal in the raw state. Pulverisation will itself play an important part in promoting the extended distillation of coal by providing a ready means for the disposal of the resulting by-product coke, for such fuel can be efficiently burnt in pulverised form even when it contains but little volatile matter.

The higher the price of coal the more necessary it becomes to cut down consumption; since, although it is rightly claimed for pulverised fuel that any grade of coal can be used in this manner, it is naturally on the high-priced fuels that the savings effected become of greatest monetary value.

By installing pulverised coal systems, the whole of the coal supply is concentrated at one or more central milling stations. All truck lines, sidings, engines, truck lifts, etc., and practically all labour for coal transport throughout a works, whether covering a small or an extensive area, are dispensed with. The daily cost of these operations in a large engineering works is referred to at p. 37.

Past and Present-day Practice Contrasted.

The numerous failures which attended the early history of fuel applied in pulverised form have earned for the subject some contempt and ridicule in engineering circles. The heavy deterioration of refractory linings; the rapid coating of boiler surfaces with an impervious insulating layer of ash slag; irregularity of fuel control; the constant fear either of spontaneous combustion or explosion, both of which frequently occurred in these early experiments, all combined to ensure failure.

In the past, the fuel was ground or disintegrated by machinery which produced what we may now term "lump dust," not always sufficiently dry, and this was fed into an air blast by means of rotary brushes, disc or table feeders, or blown at high velocity into a combustion chamber by compressed air; and the combustion chamber itself was totally inadequate in area to ensure combustion before the gases reached the boiler heating surfaces. One does not wonder at all that failure attended experiments made under such conditions.

Fuel dust in a more or less damp state would tend to coagulate, thus forming small beads much larger even than the coarser grit contained in the disintegrated fuel. Irregular feed mechanism would distribute the fuel in puffs into a strong air blast, or a compressed-air jet. There would be a direct abrasive action on refractory walls, to which fuel particles would adhere, with the natural result that fluxing of the surfaces would take place, and this fluxing action would be further increased because of the high temperature developed in close proximity to the refractory surfaces. Instantaneous combustion would result in the case of the

fine powder contained in the fuel, but the coagulated lumps and grit would either fall by gravity into the ash slag, or the finer particles would be drawn into the rush of gases, and become deposited upon the heating surfaces of the boiler, there to build up into a honeycomb mass, or glazed coating.

Now consider present-day practice. The first essential is extremely fine pulverisation, the standard being 85 % through a 200-mesh, and 95 % through a 100-mesh screen. A low air pressure is used to introduce the powdered fuel into combustion chambers, and these are now designed on very liberal lines. With fine pulverisation, adequate combustion area, and a low-pressure air supply, intimate

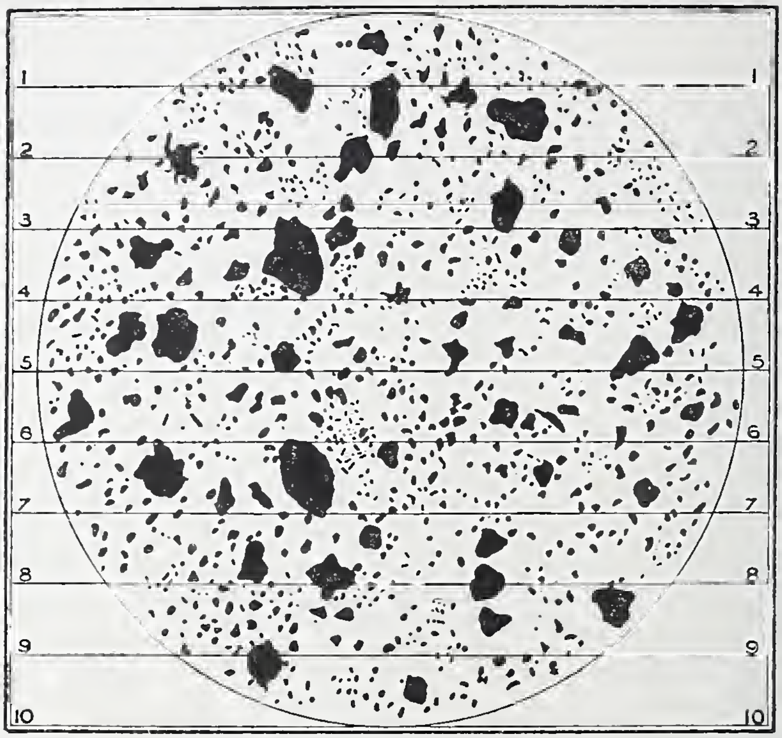


Fig. 1.—Illustration from Bryan Donkin's Paper (*The Federated Institute of Mining Engineers Transactions*, 1895–6), showing coarse Particles of Fuel in sample of 100-mesh Product (magnified 60 diameters).

mixture of the fine fuel and air is effected; the mixture is to all intents and purposes a readily combustible gas, and the soft flame resulting upon ignition has no abrasive action upon the brickwork of the combustion chamber. Ignition is instantaneous and combustion complete. The minute particles of inert material remaining after the combustible matter has flashed off either coagulate and fall to the bottom of the combustion chamber, or, in finer form, follow the flow of gases through the boiler passes to the main flue.

Faulty pulverisation under present-day conditions may still have the effect of causing unnecessary wear on refractory surfaces, and the coarse lumps will fall by gravity to the bottom of the combustion chamber, thus introducing a loss of carbon in the slag. With the low-pressure air supply, and by reason of the low

Fig. 1a.—View of Large Sheet Mill completely equipped for burning Pulverised Coal, showing entire absence of Smoke.

Quigley Fuel Systems, Inc.]

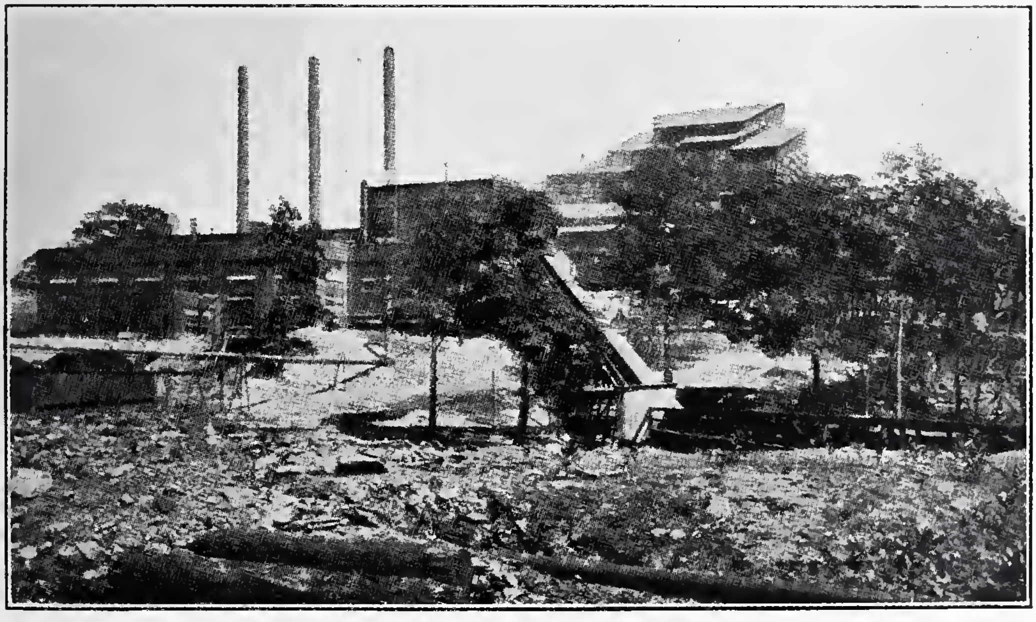


Fig. 2.—Anthracite Coal Mine using Pulverised Anthracite Culm under Smokeless Combustion Conditions.

Quigley Fuel Systems, Inc.]

[*To face p.* 6.

velocity of gases, there will be, however, little tendency for these coarser particles of fuel to be carried on to the boiler tubes. Fine and uniform pulverisation is, undoubtedly, the chief secret of the highly successful results now obtainable in such a variety of applications.

Pulverised coal installations are admittedly expensive to instal, but they cannot be termed costly if one takes into account the annual return upon capital outlay which will follow upon the substitution of pulverised coal firing for hand firing in very many instances.

Although coal in pulverised form as a fuel for firing rotary cement kilns has been in general use for twenty-five years, its successful application to metallurgical furnaces, locomotive and stationary boilers is of more recent date. American engineers have during the past ten years developed this art to such an extent that almost all industrial applications, with few exceptions, such as marine boiler firing and blast furnace applications, have been to all practical ends perfected, and can now be adopted with confidence.

Progress in America and Elsewhere.

It is a natural sequence to the initial advance made in America that that country should display the greater progress in the application of pulverised fuel. That this should be so is in a great measure important and reassuring, for it shows clearly that the economies to be obtained by burning fuel in pulverised form have been further established by extended applications in a country where coal is cheap.

Engineers in France have not been slow to follow the lead given in America, and numerous pulverised coal plants are now in operation, or in course of erection in France. This is entirely a post-war effort to introduce proved methods of increasing output, of reducing fuel consumption and works costs, and of utilising the low-grade fuels of France.

Consequent upon the due appreciation of the importance of combustion areas, of the velocity of gases, and of that very essential factor, fine pulverisation of the coal, it has been a relatively easy matter to perfect many and various applications to metallurgical, chemical, nodulising, iron, steel, and copper melting furnaces which formerly appeared to present insuperable difficulties.

The most noticeable advance of recent date has, undoubtedly, been made in the direction of burning pulverised fuel under boilers. The decision to instal this system at the new 200,000 kw. Super-Power Station for the city of Milwaukee, after thorough trial of this method as against mechanical stokers, a period of trial extending over two years, is, in itself, conclusive evidence that pulverised coal firing for boilers is receiving strong support in America. Further confirmation is now to hand in the application of pulverised coal firing for the 240,000 kw. plant of The Union Electric Light and Power Company, St. Louis, Mo. It is stated also that the Power Stations of the city of Detroit; of the Cleveland Electric Illuminating Company; and of the Detroit Edison Company are to be fitted with pulverised coal-fired boilers.

In France, the Super-Power Stations of to-day are being built for pulverised fuel-fired boilers; that at Vitry will be equipped with some of the largest boilers

in existence, viz. Delaunay-Belleville water-tube boilers on the Ladd principle, each to evaporate 185,000 lb. of water per hour at peak load.

Fuels carrying as low as 5 % of volatile combustible material are now burnt successfully as boiler-house fuel by this method, and many a railway system could advantageously employ pulverised fuel, more especially in countries where the dusty, low-value coal is unsuitable for burning on loco grates.

Experiments carried out on the Lehigh Valley Railway, U.S.A., the Great Central Railway, England, the New South Wales Government railways, the Great Indian Peninsula Railway, and the Brazilian and Swedish Government railways have suggested possibilities of great importance when once the success of this method of firing locomotive boilers has been proved. Tests, which at the time were considered inconclusive, have also been carried out on several of the railroads in America, and on the Swiss Federal Railway System. Experiments are also being conducted on the Netherlands State Railways, and by the Italian railway authorities with locomotive equipments as used on the Lehigh Valley Railway, and respectively with local low-grade coal and lignite.

Practical tests have proved that, with the standard equipment of to-day, the application of pulverised fuel to railway locomotives, when conditions are in accord with those necessary for success in relation to quality and price of fuel, and type of locomotive, can be undertaken with every confidence that very considerable economy will result. At no distant date self-contained pulverising units will be designed whereby slack coal will be pulverised as required on the locomotive tender, and the pulverised fuel fed to the firebox under equal control as in oil firing.

Pulverised coal firing, therefore, can be accepted with complete assurance of success for many uses; in other cases caution must be exercised, and consideration given to all facts before adopting this method of firing. Further investigation is required in certain directions. An idea as to the safety of introducing this system is given in the following abbreviated list of applications :—

Applications Proved Successful, or about which Sufficient is Known to Ensure Success

Cement Burning Kilns.
Lime Burning and Analogous Processes.
Iron Ore Nodulising Kilns.
Annealing Furnaces.
Puddling Furnaces.
Copper Reverberatory Furnaces.
All classes of Steel Billet Reheating Furnaces of medium and large size.
Piling and Bushelling Furnaces.
Heavy Forge Furnaces.
Sheet and Pair Furnaces.
Soaking Pits.
Galvanising and Tinning Kettles.
Railway Locomotives.

Steam Boiler Installations (Water-tube type).
Waste-Heat Boiler Firing.

The application of pulverised fuel for open-hearth steel melting is an unqualified success only when furnaces can be built in accordance with latest practice.

All applications of Colloidal Fuel Firing (mixtures of pulverised coal with oil or tar).

Applications requiring Special Consideration

Light Forge Furnaces.
Bolt and Nut Furnaces.
Rivet-Heating Furnaces.
Domestic and Office-Heating Boilers.
The Firing of Internal Fire-tube Boilers (Lancashire and Cornish types).

Applications awaiting Further Development

Marine Propulsion.
Internal Combustion Engines.
Blast Furnaces.
Fixation of Gas from total or partial distillation of Pulverised Fuel.

Self-Contained Units.

The many types of small self-contained units wherein the coal is both pulverised and supplied direct to furnaces for burning therein are small equipments which will become of ever-increasing importance. There are numerous instances where such units must prove decidedly more economical in first cost, and, also, for all practical purposes, in results achieved, than the installation of the expensive and comprehensive plant necessary for the preparation of pulverised fuel in quantities below the point at which cost of producing pulverised fuel is a reasonable surcharge upon the price of raw coal.

Great attention is being given to the design and construction of self-contained units and the field for their useful employment is certainly very extensive.

General Conclusions.

In brief the foregoing remarks are summarised in the "Conclusions" as recorded in the author's Fuel Research Board Report on American Systems :—

1. The advantages of burning coal in pulverised form have been definitely proved in actual practice.
2. The heat value of coals can be utilised to a far higher degree by this means of firing than by any other process.
3. In certain circumstances initial costs for pulverised coal plants are considerably less than the costs for installing producer gas plants.
4. Economy in fuel consumption of from 20 % to 50 % can in many cases be effected by the use of coal in pulverised form.
5. There is little or no economy to be effected by the introduction of pulverised

coal-burning apparatus in substitution for existing efficient mechanical stoker installations, but, for initial installations, pulverised coal plant can be installed at approximately the same, if not at a lower, inclusive cost, and will show increased overall economies over mechanical stokers.

6. Almost any grade or quality of fuel, anthracite, bituminous, lignite, or peat, can be used efficiently in certain circumstances in pulverised form.

7. High ash fuels, containing 30 % or 40 % ash, can in some cases be used.

8. Large quantities of what is considered waste coal can be used to good purpose, and culm and slack heaps at mines can be at once turned to profitable account.

9. In suitably designed plants there is practically no danger whatever of the possible explosion of coal dust.

10. With the precautions as to limited storage recommended there are no apparent difficulties with regard to spontaneous combustion.

11. The slag or dust resulting from the ash in coals can be conveniently and effectively handled and removed from all classes of melting and heat treatment furnaces, stationary boilers and locomotives, small furnaces, such as rivet-heating furnaces being an exception.

12. A very important start has been made in connection with the firing of large power-house boiler plants. The results given at the new 200,000 kw. Super-Power Station at Milwaukee certainly indicate that this method of firing power-house boilers is likely to develop with increased rapidity.

13. In view of the continued interest on the part of important shipping companies in this system of firing marine boilers some progress is to be looked for in the near future.

14. Owing to the very considerably reduced amount of labour incidental to a pulverised coal plant, as compared with hand firing and, in certain cases, stoker firing, the labour saving is a most important feature introduced by this system of burning coal. Saving in labour is particularly marked in connection with the firing of railway locomotives and, incidentally, conditions are greatly improved for the operators.

15. In view of the smokeless combustion of pulverised coal in metallurgical furnaces, and especially in puddling furnaces, for boiler firing and for locomotives, the abatement of smoke nuisance in large cities by this means can be accomplished to an appreciable extent.

These brief remarks will serve to introduce this subject to readers and to place before them some of the important matters that go hand in hand with fuel economy in industries of all countries, but before terminating these introductory notes there is one matter to which attention should be drawn, for in order thoroughly to investigate, locate, and remedy wastage of fuel and heat leakages, managements of industrial and engineering works would do well to adopt another established American practice.

Efficiency Engineers and Everyday Losses in Fuel Burning.

One of the essential members, if not the most important official, of the engin-

eering and production staff of an American organisation is the Efficiency Engineer. His duty is to hold a watching brief on behalf of the management to see that every precaution is taken to eradicate waste and loss of output.

An Efficiency Engineer is a fully qualified engineer, specially trained in the detection of leakage in the broadest sense, not only such leakages as those of steam at badly-made pipe joints, which loss is apparent to everyone, but also the far more serious leakages of power, which are invisible and indeterminable without complex investigations. Efficiency Charts, recording instrument diagrams, process curves, etc., tell the story to the Efficiency Engineer.

The Efficiency Engineer commands a high salary, and rightly so, for through his detecting influence and energies far-reaching improvements in the running of a works or plant may and do result in monetary savings far exceeding the remuneration given for his services.

An Efficiency Engineer should be attached to the staff of every industrial works producing big output, whether of textiles, food-stuffs, chemicals, iron or steel, or any other commercial material.

In this book, dealing more essentially with the economical application of fuel, it is unnecessary to review the multitudinous ways in which an Efficiency Engineer can effect savings. Such matters as the improved alignment of shaftings, the manner in which journals and bearings should be lubricated or fitted with rollers or balls to reduce friction losses, the raising of the mechanical efficiency of machinery by substitution of improved types, etc., lie outside the scope of direct fuel economy.

In the matter of applied heat from fuel the Efficiency Engineer can tabulate recorded fuel consumption per 1000 lb. of steam raised, ton of steel ingot or rolled steel joists produced, ton of puddled iron, steam raised by waste heat, so that best recorded results under certain periodical conditions can be made more general, or means taken to eradicate positive waste.

In other ways, the overhaul of steam mains, or compressed air lines, insulation of boilers or heaters, are all questions that it should be the business of the Efficiency Engineer to bring to the notice of the proper authorities; it then comes into the province of the Works Engineer to carry into effect the proposals to which sanction has been given.

Some of the matters which come directly into the category of "Sources of Waste" in connection with fuel applications were referred to in some articles published by the author in *The Textile Recorder*, from which the following notes have been taken.

Coal for industrial furnaces contains anything from 8 % to 15 % of moisture, and in mechanical stokers, or with hand firing, the fuel in this wet condition is fed directly on to the burning fire.

It may be taken that for every 1 % of moisture the calorific value of coal will be decreased by 12·5 B.Th.U. per pound of fuel, which represents the amount of heat required to evaporate the water and superheat the resultant steam.

Thus, with a coal containing 10% moisture as fired, 125 B.Th.U. will be lost in every pound of coal fired. Assuming coal of 11,000 B.Th.U. per pound, costing

30*s*. per ton, and one boiler using 2500 tons of coal per annum, the loss per boiler per annum will be equivalent to about £42 10*s*. in fuel value.

The Efficiency Engineer would suggest that the fuel should be kept dry, not only with regard to the coal in the main depot but also throughout the works, and devise means for doing so.

The loss of heat energy due to the above and other elementary causes are referred to at pp. 85 to 99, and in order to emphasise the money value of such loss of heat energy the Efficiency Engineer can prepare an indisputable estimate of the precise waste arising from various causes due to inefficient hand firing, even for the small steam plant of an industrial works, as referred to at the later pages mentioned.

It is assumed that the boiler plant consists of three 8 ft. × 30 ft. Lancashire boilers, two of which are always working and one kept as standby, the working pressure being 150 lb. per square inch without superheat, the coal used being of 11,000 B.Th.U. value, with 20 % ash, costing 30*s*. per ton in the boiler house, and hand fired with an overall thermal efficiency of 65 %.

The following losses, with their equivalent value per annum, will occur under the conditions accepted, which are quite normal for small factories :—

	£	*s*.	*d*.
Loss due to excess air supply to furnace	1650	0	0
,, ,, unburnt carbon in ashes	300	0	0
,, ,, smalls and dust lost in stokehold	37	10	0
,, ,, moisture in fuel	85	0	0
Total for two boilers	£2072	10	0

The introduction of CO_2 Recorders for three boilers at a cost of, say, £300 would be a means of eliminating much of this waste, whilst pulverised coal firing might conceivably remove nearly the whole of the losses cited, and, at the same time, increase the efficiency, steaming rate of boilers, reduce labour, cartage, ash handling, etc.

The accumulation of soot on boiler surfaces is another question of some importance and is referred to again on p. 81. With hand or stoker firing it is to a large extent a relatively easy matter to remove many sources of fuel losses, such as excess of air, radiation, leakages in brickwork settings, etc., but the reduction of the efficiency figure due to the deposition of an insulating coating of soot upon boiler tubes and surfaces is not so easily overcome.

The formation of smoke is inevitable to some extent with hand firing, and the soot or semi-ash particles passing off with the products of combustion build up an insulating coating on the boiler surfaces. If allowed to accumulate, this deposit will form into a hard clinker or slag covering, rendering those portions of the boiler tubes enclosed thereby almost inoperative. Not only is soot detrimental to the boiler, but it will also cover economiser tubes, thus again lowering the overall efficiency of the steam-raising plant.

Experiments have proved that a layer of soot one-sixteenth of an inch thick on a boiler surface reduced the total heat conductivity of the plate by over 25 %, soot being one of the best heat insulators known, and, in this respect, about four times as effective as asbestos. So that if the thermal conductivity of the boiler-heating surfaces be reduced by 25 % over a half of their effective area, the steaming rate of the boiler will be correspondingly reduced whilst maintaining the same fuel consumption, or, conversely, more fuel will have to be used to obtain the same steam output.

If the output of a 30 ft. × 8 ft. Lancashire boiler be 6000 lb. of steam per hour when burning 760 lb. of coal per hour with clean boiler surfaces, this equals an actual evaporation of 7·9 lb. per lb. of coal. If, however, owing to soot and tar deposits, the thermal conductivity of half the equivalent heating surface of the boiler be reduced 25 %, the steam output will be reduced to about 5250 lb. with the same coal consumption, or to maintain the output of 6000 lb. the coal consumption will have to be increased to about 870 lb., an increase of 110 lb. per hour, which, in fifty weeks, of one hundred and forty-four hours, represents 350 tons per annum, and at 30*s*. per ton equals £525 per boiler. The waste due to soot accumulation can thus be appreciable, and any improved method of fuel burning, whereby smoke, soot, and tarry deposits on the heating surfaces can be avoided, properly appraised as a means of direct economy. The installation of soot blowers would greatly reduce this loss, but *by burning coal in pulverised form* the combustion is almost instantaneous, and is so complete that not more than ½ % of combustible matter remains in the dust or ashes; consequently, *there is no smoke, no sticky hydrocarbons or soot*, and any dust carried over to the flues or tubes is in the form of fine powder, so that it can be blown away by air jets from all surfaces at regular intervals, thus maintaining clean boiler-heating surfaces and largely eliminating the very serious loss just indicated.

The losses due to uncovered pipes, leaky joints, steam valves, etc., are losses the value of which is frequently overlooked. The higher the steam pressure the hotter the steam pipes will become, and, consequently, the greater will be the loss from uncovered surfaces.

Consider the case of a steam-pipe line from a single Lancashire boiler with a steam pipe, say, 8½ inches external diameter. If the total length of steam pipe is 150 feet from boiler stop valve to engine stop valve, a total surface of 325 square feet is exposed to the atmosphere. Take the average loss value to be 3 B.Th.U. per square foot, per hour, per degree Fahrenheit difference in temperature between the pipe surface and atmosphere, and an average atmospheric temperature of 60 deg. Fahr. With steam at 150 lb. pressure equivalent to a temperature of 366 deg. Fahr., *i. e.* 306 deg. Fahr. higher than the surrounding atmosphere, we have a loss of 918 B.Th.U. per hour, per square foot of exposed pipe, or 918 × 325 = 298,350 B.Th.U. per hour for the whole pipe line. With coal of a calorific value of 11,000 B.Th.U. costing 30*s*. per ton the dead loss due to radiation would cost about £200 per annum—the equivalent heat of 41·7 lb. of coal per hour being wasted in this manner in raising steam in the boiler at 65 % efficiency.

There are probably few steam installations in existence at the present day

where whole lengths of main steam pipe are left totally uncovered, but in almost every steam plant can be found odd lengths of uncovered pipe, the total surface area of which must be responsible for heavy losses due to radiation. By covering with a 3-inch layer of magnesia or other suitable covering, the loss can be reduced to something less than one-tenth of that with uncovered pipes. In many instances it has been found possible to reduce very appreciably the load on the boilers by merely covering exposed steam pipes with suitable heat-insulating material.

Now, taking the case of leaky joints, if there is a leak equivalent, say, to one pint of water per hour on a steam pipe carrying steam at 150 lb. pressure, this would equal a loss of heat of 9000 B.Th.U. per hour. With coal of 11,000 B.Th.U. value burnt at 65 % efficiency, 1·3 lb. of coal per hour would be used to evaporate the steam escaping at this leak. Thirty such joints leaking in a steam plant would mean a waste of 125 tons of coal per year, which, at 30*s*. per ton, equals £187 10*s*.

It will therefore be seen that uncovered steam pipes and leaky joints are a source of very serious loss in many steam plants; in fact, several instances have occurred where by due attention to uncovered pipes, leaky joints, and valves, the number of boilers in operation has been reduced when these sources of steam loss have been removed.

All these and other matters should receive the daily attention of the Efficiency Engineer, and the collective economy and saving that he effects will always be worth while in a large works.

CHAPTER II

REASONS AGAINST THE USE OF PULVERISED FUEL

Spontaneous Combustion, Explosion, and Storage Difficulties—Transportation—Reabsorption of Moisture—Preparation Costs—Capital Expenditure.

Much has been written about the merits and advantages of pulverised coal. On the other hand, what are its drawbacks, and how are these objections answered?

On this side of the question the author would enumerate some of the disadvantages, which, in particular, are usually put forward as being insuperable. The difficulties and disadvantages as these would apparently present themselves to an investigator of the subject are briefly :—

1. Spontaneous combustion, explosion, and storage difficulties.
2. Difficulty of transportation.
3. Reabsorption of moisture.
4. Preparation costs.
5. Capital expenditure for comprehensive plants.

Spontaneous Combustion, Explosion, and Storage Difficulties.

Due consideration and thought must be given to the quality of fuel to be pulverised and stored. The length of time that storage is feasible or safe depends on the nature of the fuel, the temperature at which it is delivered into the storage bins, and its initial content of moisture and volatile matter. Anthracite is the safest coal, whilst lignite is the most dangerous, the ordinary bituminous coal being intermediate.

The danger of explosion is a disadvantage, but not more so than that appertaining to coal gas, or even to oil. The danger of explosion in a mill house exists when leaky and faulty plant is permitted to exude coal dust into the atmosphere. This can and should be prevented. In very exceptional circumstances the pounding of a nut, or broken beater arm, in a "dry grinding" mill until the metal fragment becomes red or even white hot, may ignite the coal dust and air mixture in the mill and cause an explosion, but this is a very remote possibility, although accident has occurred through this cause. For this reason slow-speed rotary mills fitted with grinding rings are perhaps preferable to the higher-speed beater-arm type of machine.

It has been suggested that the danger of using pulverised coal is analogous to the danger existing from coal dust in a mine. A coal-dust-laden mixture explosion in a colliery working must be likened to the actual burning of pulverised fuel in air inside the combustion chamber of a furnace. It affords no ground for the

suggestion that because of colliery explosions pulverised coal is in itself a dangerous and explosive substance. Recent explosions in America in connection with pulverised coal equipment have been generally due to mixing and conveying the fuel in air, and, therefore, under conditions analogous to those occasioning explosions in collieries.

To explode or burn pulverised coal it must be mixed with the requisite amount of air, but where the powdered fuel is conveyed by mechanical means the air supply is introduced only at the furnace burners, or at most through short lengths of small piping, in cases where the fuel must be previously mixed with air.

Pulverised coal forms a highly explosive or inflammable " gas " only when it is intimately mixed with air, and it is essential that every care should be exercised to see that adequate and commonsense safeguards are taken to prevent or eliminate the risk of explosion. Pulverised coal can be handled as a semi-solid or fluid with ease and safety, and has been so handled, conveyed, and brought to the point for combustion without breakdown or accident for many years in numerous plants operating in America and elsewhere. Pulverised coal is no more dangerous than finely-ground flour in a corn mill, and it is perhaps even less dangerous than oil or gas, with all of which recognised and established precautions against accident are essential.

In America, in July 1920, a serious accident occurred at a sheet steel works, and five men succumbed to injuries through burns following upon an explosion in a faulty pulverised coal system. It is not merely folly but criminal folly to instal a pulverised coal plant which is not constructed upon acknowledged and safe principles.

On this subject of explosion with pulverised fuel, so long ago as 1915, when the design of pulverised coal equipment had not received the attention given to it to-day, the opinion of the Thos. A. Edison Company was sought as to the causes of explosions which had been experienced in cement works in America when pulverised coal had been used. The following is the reply received :—

" With reference to the explosion of pulverised coal in cement plants, we have been building cement machinery for many years and built some of the first cement plants installed in this country where powdered coal is used. The accidents that occur in these cement plants, which are very seldom, are due to allowing pulverised coal to lie in storage where it catches fire by spontaneous combustion and the resultant gas accumulates in dead spaces where it finally becomes ignited and causes the explosion. In nearly every case it is not a dust explosion. The worst accident in a cement plant that I know of was at the Edison Portland Cement Company, and I have the following letter from Mr. Edison, which shows that this explosion was caused by gas and not powdered coal. I know of a great many cement plants using powdered coal that on account of taking ordinary precautions have never had an explosion or even a fire."

The letter referred to from Mr. Edison himself was as follows :—

" I beg to say that the explosion you refer to was occasioned by fine coal dust

catching fire and burning slowly in a pit, thus forming an explosive gas with the air. This exploded and killed five men. Please let me emphasise the fact that it was not the dust itself that exploded."

Some pertinent notes relating to the dangers of using pulverised fuel were printed in the *Times* of India, May 7th, 1920, the substance of which is given below.

The question of the explosion and spontaneous combustion of pulverised coal is often advanced as a serious argument against the use of this class of fuel, and many engineers hold very exaggerated ideas on the matter.

It is true that, at various times, more or less disastrous explosions and spontaneous combustion troubles have occurred with pulverised fuels, but these can be traced to carelessness or lack of proper precautions in designing or operating the pulverised fuel plant. It is well known that any finely divided carbonaceous matter intimately mixed with air will explode; perhaps one of the commonest examples is the atmosphere in a flour mill where proper precautions are not taken to eliminate dust. In the past, a number of very serious explosions have occurred in flour mills before the need for care in eliminating dust was fully realised. At the present time, however, such explosions are exceedingly rare, and the use of pulverised fuel from the point of view of a dusty atmosphere is no more dangerous than a modern flour mill, if the pulverised fuel equipment is properly designed.

The greater number of pulverised fuel explosions have been due to using apparatus designed on unsafe principles; perhaps the most marked of which is the use of air currents of high velocity, for transporting the pulverised fuel in suspension, in large diameter pipe lines. This is a system having certain operating advantages, but a great many more disadvantages, and is a source of potential danger from explosion.

Pulverised fuel preparing and burning equipment is now made which is as near as possible fool-proof and free from any reasonable explosion danger; so that if worked with even ordinary care no trouble or danger will be experienced in this direction.

The other question of spontaneous combustion is also very largely dependent on the way a plant is operated. There is no question that pulverised coal will ignite spontaneously more readily than lump coal, but, if correctly handled, no such trouble need be feared. The spontaneous combustion of fuel depends on a number of factors, including the quality of the fuel, and is hastened under certain physical conditions.

The absorption of oxygen by coal is more rapid in proportion as the oxidisable surface exposed per unit of weight is increased, so that if finely divided coal is exposed to the atmosphere its increased liability to spontaneous ignition is in direct relation to its increased fineness of division as compared with the original lump coal. Apart from this, however, lump coal and pulverised coal are equally subject to spontaneous ignition.

In practice, pulverised coal is not exposed to oxygen per unit of surface to anything like the extent that lump coal is, because it packs together in bins, etc., to such a degree as to exclude very largely the oxygen of the atmosphere; so that the

effect of very fine grinding is largely offset in this respect. Two of the factors that increase the tendency to spontaneous combustion of coal are heat and damp. For this reason pulverised coal should not be fed into storage bins at a high temperature from the dryer and the mill, otherwise the contained moisture condenses in the bins and runs down to the bottom, where the trouble may be aggravated by a leakage of air into the bins through faulty joints. It is at the bottom of bins that most cases of spontaneous combustion have occurred.

If, however, pulverised coal be stored in bins of reasonable size to allow the heat generated to be dissipated, and if due attention be paid to the joints, no trouble will be experienced from spontaneous combustion. As a proof of this, it may be mentioned that, in well-operated plants in America, fuel has been stored in pulverised form for several months without deterioration or fire.

The author found no single instance in America where any special precautions had been taken against explosion of coal dust other than those dictated by commonsense. Installations had been in use without any explosion having taken place for so many years that the danger of explosion had almost been forgotten.

In some of the older plants the pulverising mills, bins, girders, stairs, elevators, etc., were thickly covered with coal dust, which if dislodged over the open fires of driers erected in the same building undoubtedly would have become ignited. Unnecessary risk of fire, even if not of actual explosion, was being openly courted in those plants.

Bins for the supply of coal dust to open-hearth furnaces covered with coal dust, and erected close to the ends of adjoining furnaces, had been in use under these conditions for many years. So close were these bins to the furnaces that, owing to heat radiated through the open joints of the furnace and walls, the bins were quite hot to the touch, and yet at these works no fire, flare, or explosion had ever taken place.

The existence of such dangerous conditions actually within the mill house laden with the dust from pulverisers, and with exposed dryer fires, without any mishap having occurred over several years in some cases, reassured the author, and should reassure those who are excessively fearful of coal-dust explosions, that, given ordinary safeguards, pulverised coal plants are far less dangerous than might be imagined.

In buildings where furnaces are situated, the roof trusses and over structure above furnaces should be periodically cleaned. In one or two cases it has been reported that flares have occurred due to painters having dislodged coal dust from the trusses and loose planks that had lain for some time over the furnaces. The dislodged coal dust, mingled with the air inside the building, had lingered in its fall and the explosive mixture thus formed had ignited at the open doors of the furnaces. But happenings such as these were not regarded with any degree of anxiety.

At the new plants, greater attention has been given to keeping the mills and mill house clean; in fact the new types of mills, and the care now given to design of plant, make for a dust-tight equipment, and practically eliminate any chance of fire. With due exercise of commonsense there is, therefore, no danger of explosion either in the mill house, throughout the coal-dust transport system, or at the furnace.

C. P. Beistle, Chemist of the Bureau of Explosives, U.S.A., has also contributed

to the investigation of this subject, and in an article in the *Railway Age Gazette*, October 12th, 1917, he writes :—

" The pulverised coal should be stored in metal bins or receptacles sufficiently tight to prevent circulation of air or the entrance of moisture. The amount of pulverised coal kept in storage should be as small as is practicable, considering the daily consumption : the reserve of fuel should be stored in the lump condition and not as pulverised coal. In case pulverised coal ignites spontaneously, or from any other cause, it burns slowly with smouldering combustion, and if kept in tight metal bins is not liable to cause much loss.

" In common with other combustible dusts, such as flour, elevator dust, etc., under certain conditions coal dust or pulverised coal is capable of producing violent explosions. This explosive action can take place only when the dust is suspended in the air, and then it requires the contact of a spark or flame for ignition.

" Storage bins, driers, pulverisers and conveyors should be tight to prevent the escape of the pulverised coal into the atmosphere. Coal dust should not be allowed to accumulate on exposed surfaces inside of buildings or in other places where by any means it may be thrown into the air to form a dust cloud.

" No lights other than incandescent electric lights provided with heavy guards should be permitted in places where pulverised coal is being prepared, handled or stored. Fires, matches, lanterns or torches should not be permitted in or around pulverising mills or storage bins.

" The inflammability of pulverised coal depends on the proportion of volatile matter in the coal and, therefore, bituminous coal is more dangerous in this respect than anthracite coal, and lignites are more dangerous than bituminous coal. While pulverised anthracite coal is not liable to spontaneous ignition and is less liable to produce dust explosions than other coal, the coal commonly pulverised for use as fuel is bituminous coal or lignite, as pulverised anthracite coal has not yet been successfully applied as a fuel, except when mixed with softer coal."

Hudson Maxim, whose name is known throughout the scientific world, has also given his conclusive opinion as to the small danger that exists of explosion due to storage of pulverised fuel in the following paragraphs :—

" Lastly, there will be and can be absolutely no danger whatever from spontaneous combustion. It is impossible for coal to burn without air and it requires twelve pounds of air to burn one pound of coal. In the bunker cylinders the volume of pulverised coal and air will be about equal to each other, that is to say, each cubic foot of pulverised coal contains voids filled with air about equal to the actual bulk of the coal itself.

" A cubic foot of air weighs one-twelfth of a pound at atmospheric pressure, and one-half of a cubic foot, therefore, weighs one-twenty-fourth of a pound. The weight of a cubic foot of pulverised coal is about forty pounds, so that we have in a tank only one-twenty-fourth of a pound of air to burn a cubic foot of coal, instead of twelve pounds of air per pound of coal, or four hundred and eighty pounds of air,

the quantity needed to burn forty pounds of coal. Twenty-four times four hundred and eighty is 11,520, so that there is not one eleven-thousandth part of the air present necessary to burn the coal.

"That such a limited quantity of air would be able to support the combustion of so much coal is utterly absurd.

"Furthermore, one of the most efficient fluids for extinguishing combustion is carbon dioxide, and immediately, should there be any combustion of coal in a closed cylinder, carbon dioxide would be generated and the gases of the burning coal would, therefore, very quickly extinguish the fire.

"The impression that pulverised coal is liable to spontaneous combustion arose from the fact that if pulverised coal be exposed to the air in such wise as to admit of free contact and circulation of the air, oxidation of the pulverised coal will take place and heat will be generated, and if the heat is not permitted to escape freely it will very likely rise to the temperature of ignition, and the coal will fire and be consumed, for the products of combustion will be permitted to escape as fast as formed and fresh air admitted to the fire.

"But such conditions do not and cannot obtain in a closed steel cylinder, consequently there is absolutely no danger from spontaneous combustion of coal in closed steel cylinders."

Although Hudson Maxim's notes referred to the particular method of storing pulverised coal in closed steel cylinders on board ship, the arguments used may equally well be applied in a general way to the storage of pulverised coal in the semi-enclosed type of bin usually adopted for land installations.

On the dangers of pulverised fuel, A. B. Helbig has written many valuable notes, from which the following has been extracted. After pointing out that the inexperienced person always asserts that the handling of pulverised fuel is especially dangerous, whereas the expert is nowadays of opinion that, with proper care, it is no more dangerous than the work in any other kind of factory, he says :—

"It has risks, it is true, but a knowledge of the dangers and their sources is a safeguard against serious consequences. It has been thought that the disasters occurring in mines owing to dust explosions would have their counterpart in the pulverised fuel industry, a view which leaves out of account the fact that the working conditions of a mine cannot be compared with those of a coal mill, unless no attempt is made to clear the mill of dust. A preliminary condition for a dust explosion is the uniform distribution in the air of a definite quantity of the very finest dust. If there is too little dust in the air its combustion temperature is not sufficient to spread and sustain a further combustion. The fire goes out. If there is too much dust the flame dies out, partly from want of oxygen, partly because the mixture requires so much heat that the ignition temperature is not reached. In the normal working of the pulverised fuel mill there is always far too much dust in the mixture of dust and air so that no explosion can take place.

"In order to avoid accident through burning or explosion when lighting up a furnace, coal dust must not be blown on to the wood fire or primary warming up fire

too soon, and only when the fire is burning properly and the ignition chamber is properly warmed must the feeding in of the fuel be started with a very small quantity of dust, with exactly the same precaution and in the same manner as for oil firing.

"With badly constructed fuel feeders it may happen that the fine pulverised coal will flow like water through the feeder and literally inundate the firebox. In this case an explosion of the mixture or evolved gas is possible and has occurred. It is very essential, therefore, to instal well-designed feeder equipment. Every coal milling house should be thoroughly swept out daily, or at the very least every three days, care being taken to clear out all dust deposited on roof ties, wall projections and in corners. Pulverised fuel, especially coal dust, and above all brown coal and peat dust, long exposed to the air eagerly absorbs oxygen and conducts the fire like gunpowder. Most of the fires and explosions in coal mills have taken place when they were not working. The fundamental condition for a well-planned and well-managed pulverised fuel plant is that the dust be completely shut off from the air. The advantage of dust as against gas is that any chance leakage is at once visible and easily remedied, and an escape of dust is much less dangerous than an escape of gas."

With screen separation or tubular mills there is little danger of explosion in the mill due to incandescent particles of fuel; in fact, Helbig says that he has in many cases allowed dry coal with incandescent particles to run into the tubular mill, quenching it with water in critical cases.

When air separator mills are employed, the operation must be stopped immediately incandescent coal appears, as the critical explosive dust and air mixture can be readily formed when air currents are employed as the medium for extracting the fine fuel, and explosion valves should always be provided with this system.

As regards removal of coal dust in a mill house, this should preferably be accomplished by vacuum suction and delivery arranged into a cyclone separator with auxiliary "bag house" to catch the very fine particles. Special fireproof filters have been designed for this purpose, and are run in series. Dry filters are used for coarse filtering, and wet filters for the final and complete removal of fine dust.

Summing up the dangers of pulverised fuel works, A. B. Helbig concludes as follows :—

"All the experts whose verdict has come to my knowledge are of the one opinion which, shortly summarised, is as follows : Pulverised fuel in air-tight iron or concrete containers is not dangerous. Coal dust from certain grades of fuel long exposed to the air becomes easily inflammable, owing to self-oxidisation, therefore scrupulous cleanliness is necessary where coal dust is handled. Coal dust becomes explosive only when mixed with air intimately and in a definite proportion; therefore, when cleaning platforms, roof ties, etc., unnecessary stirring up of the dust must be avoided. The pulverised fuel injected into the firebox must take fire at once, so as to keep the ignition explosion within safe limits as for oil or gas firing.

"If these precautionary measures be conscientiously observed, pulverised fuel working is no more dangerous than that of any other fuel. Here, as everywhere else, indifference and carelessness are the chief sources of danger."

The rapid progress that has taken place in the installation of efficient and reliable systems is ample evidence as to the safety and success of this method of firing.

Perhaps the more readily accepted reason for several accidents is the ignition of an explosive mixture of air and fuel in mains used for conveying pulverised fuel in air. It has been conjectured that, by reason of a falling off in pressure, the velocity of the air and coal-dust mixture in a trunk main was reduced, that a back flash from one of the working furnaces ignited the mixture in the branch pipe, and this, in turn, fired the main supply right through to the cyclone separator and coal storage bin at the mill house. Or again, another cause which has been suggested for accidents occurring where the air and coal-dust mixture conveying system has been adopted is the spontaneous combustion of coal dust deposited in the main pipe, the smouldering fuel having been fanned into flame after a period of shut down when the circulating supply system was restarted.

So many accidents have occurred with this system for one reason or another that only when safety can be reasonably assured should the air and coal-dust mixture system of supply to furnaces be used. There are now many safe systems of transporting pulverised coal, so that this danger can be entirely eliminated. Carelessness on the part of operators is the one elusive factor over which there is no mechanical control.

On the question of storage, A. B. Helbig writes :—

" Like every other factory running twenty-four hours in the day coal milling depends on the uniform feeding of the material, in this case the combustible, to be dealt with, and the bigger the intermediate and final storing tanks the more is the total output of the mill independent of the chance failure of any one machine. In the numerous plants for turning out pulverised fuel which have been designed under my direction I have, wherever it could be afforded, built dust-storing tanks of sufficient dimensions for forty-eight and seventy-two hours. The storing up of coal, even for a considerable period, is perfectly safe, provided care be taken to clear the container completely, even of wet coal, and to see that there are no corners in which it may lodge and, becoming in course of time heated, finally take fire.

" If ever in a large coal-dust container the coal began to glow, which is the most that ever happened, the dust was simply fired, access to the container and all ventilation pipes shut off, the silo run empty and thoroughly swept out, the air being first carefully exhausted and several times renewed. Fierce fire or explosions cannot arise in closed containers, owing to the absence of the necessary oxygen. What oxygen is present is at once consumed and goes to form the best fire extinguisher —carbonic acid. For this reason I do not hesitate, contrary to many other experts, to recommend large pulverised fuel containers."

In America, twenty-four hours' supply of pulverised coal is perhaps the usual limit of storage, and plants are designed with this end in view. This is a safe precautionary measure only, and, on occasions when pulverised fuel is to remain for weeks in storage, daily inspection of the lower parts of bins should be made to see whether any heating is taking place. Should there be overheating, the fuel can no

doubt be despatched to the furnace bins, during which operation the coal will be cooled down and can be retained for further time in storage. Serious overheating in time at the furnace bins entails the burning off of the hot fuel, or withdrawal by some other means.

Many instances have occurred where through some cause or other pulverised coal in 30 to 60 tons bulk has been stored for three or four months without any sign of spontaneous combustion. The usual effect of spontaneous combustion in a pulverised coal bin is to produce a caking together of the fuel in the centre of the bulk. Actual fire is ultimately self-extinguished in the manner described by Hudson Maxim in the foregoing notes, owing to absence of sufficient oxygen to support combustion, and by the generation of CO_2 gas.

At the furnace end of fuel supply, bins holding 10 or 15 tons of pulverised coal have lain charged, for many weeks in some cases, without ignition, in others, fires have occasionally occurred over-night, producing " central caking " in the coal bin. In the latter cases, the coal dust has either been discharged and taken away, or it has been fed direct into the furnaces. Hot or caked coal can be carried through the feeder screws to the burners without damage to the apparatus, and without shutting down to clean out the bins. The safe period for storage at furnaces is governed by actual experience with the class of coal used. It is considered good practice to store only sufficient coal at the furnace bin to last for one shift, eight hours or so.

Transportation.

The conveyance of pulverised coal through a works was until recently a troublesome matter, but the difficulties no longer exist; the compressed-air transmission through ordinary 3-inch or 4-inch pipes, and the pumping system through similar pipes, have made the conveying of pulverised coal both easy and safe.

Reabsorption of Moisture.

In wet climates, the reabsorption of moisture may well result in the blocking of conveyor pipe lines, and possibly in the commencement of spontaneous combustion in storage bins. For such countries, screen separator types of pulveriser mills should be used, for with these there is a minimum of moisture-laden air in contact with the fuel in the mill. For the same reason, coal dust cannot possibly be conveyed in an air current through trunk mains, and screw conveyors which also contain much air space should be avoided. The quantity held in storage at all points should also be a minimum; in fact, pulverised coal in wet climates should be burned as soon after it is " made " as possible.

Preparation Costs.

Preparation, and conveying and burning, costs, together with an allowance for interest on capital, must always be added to the cost of raw coal, and at the relatively high yet differing rates for labour obtaining in most countries at the present day, overall preparation costs vary considerably. Whether fuel of a cheaper quality

can be used for equal duty, or whether reduced consumption of standard grade coal, plus other savings, outweigh the increased cost of pulverised fuel for any capacity of plant, are matters for calculation and are fully reviewed in Chapter X.

Capital Expenditure.

The greatest disadvantage is the heavy capital expenditure involved. If £10,000 per annum could be returned on an expenditure of £100, every consumer of fuel would put down a plant, but when, to obtain an estimated and realisable return of £10,000 per annum as increased profit, existing plant must be scrapped and an outlay of £10,000, or £20,000, on new plant be incurred, it is only reasonable that a would-be user should require to be firmly convinced on all points before making the change. Until either design of complete plant is modified in order to lower the initial capital cost, or until the few plants already installed can be referred to as giving unqualifiedly successful and economical results in England and in Europe, the general adoption of pulverised coal will perhaps be somewhat slow. But American practice has proved that production costs can, in some cases, be reduced 50 % by the use of pulverised fuel.

CHAPTER III

NATIONAL ECONOMIC VALUE OF SOLID FUEL

National Welfare Dependent upon Economic Production—Reduction of Imported Coal—National Consumption of Coal and Utilisation of Low-grade and Waste Coal—Distillation of Coal—Incidental Claims for Utilisation of Pulverised Fuel —Concentration of Coal Supplies.

The national welfare of every country is dependent upon imports and exports expressed in currency values of the country. A healthy situation exists only when the total export value exceeds the total import value, and every effort is made to foster the excess.

The most important question in every country is the cost of its industrial fuel. From the very commencement of economic production, even in the winning of coal, the consumption of fuel takes place, and the burning of fuel continues throughout the various stages of manufacture. The fuel question also enters very seriously into transportation costs. This multiplication of the uses of fuel carries with it an ever attendant wastage of fuel due to inefficient methods of burning fuel for heating furnaces, or for firing locomotive or stationary boilers.

In addition to actual wastage losses, it may be necessary to take into account the price of imported coal, often a very high figure. The gross value of exported goods is no real criterion of the prosperity of industry in a country into which coal has to be imported, or in which the price of coal has risen to such an extent as greatly to increase all the other costs. Under such conditions total figures for goods exported may be quite misleading, the real economic position being hidden by inflated values.

Notwithstanding that it is of world-wide importance, the scientific use of fuel is not sufficiently realised, and far greater attention must be given to the conservation of unmined coal, and to the reclamation of much useful fuel now considered waste, than these have yet received.

The art of pulverising and burning almost every class of coal, lignite, and peat, not excluding the so-called " waste coal," washery culm, fine dust, screenings, etc., often containing 30 % to 40 % of inert material, has been thoroughly developed in the United States of America during the past ten years.

In 1920, the consumption of fuel in pulverised form in America was not far short of 18,000,000 tons, and it is safe to assume that by this means between five and eight million tons of coal, that would otherwise have been burned under the older methods of hand-fired grates, stokers, or in gas producers, have been saved annually since that year. The average eost of industrial coal is about \$2·00 per ton, and this means that American goods have been produced at a cost of \$10,000,000

to $16,000,000 below the cost of production prior to the introduction of pulverised fuel systems.

In order to apply fuel in pulverised form, it is necessary to crush, dry, pulverise, and convey it to the burners. This cannot be accomplished without the expenditure of capital upon the necessary plant. Practice has clearly shown, however, that the whole cost of machinery and equipment can be recovered out of the collective savings in fuel, reduction of labour, increased output of furnaces, etc., within a very short period of working, especially so when the cost of coal is relatively high.

Reduction of Imported Coal.

The annual coal bill of Switzerland, a country which possesses no high-grade coalfields, has been during the past few years as follows :—

1913	Frs.	107,000,000	for imported coal.
1914	,,	100,000,000	,, ,, ,,
1915	,,	125,000,000	,, ,, ,,
1916	,,	151,000,000	,, ,, ,,
1917	,,	159,000,000	,, ,, ,,
1918	,,	312,000,000	,, ,, ,,
—		—	
1920	,,	600,000,000	,, ,, ,,

Of the 600,000,000 francs paid by Switzerland for imported coal at the inflated prices of 1920, an appreciable financial saving could have been made by burning much of this fuel in pulverised form, and a further reduction could have been effected by the substitution of local low-grade fuel for the costly imported coal. The quantity of fuel thus saved would either have been available in Switzerland for an increased output of manufactured goods, or that amount of coal not required by Switzerland would have been left in the mines of the country of origin. In the one case, the value of Swiss exports would have been increased, and, in the other case, a corresponding reduction in imports.

In 1919, France purchased some 19,000,000 tons of coal from abroad as follows :—

From England . . .	15,000,000 tons.
,, Germany . . .	1,050,000 ,,
,, U.S.A. . . .	420,000 ,,
,, Ruhr Basin . .	2,500,000 ,,

The lignite fields of France should be called upon to provide a big percentage of the fuel now purchased from abroad.

Fuel of the poorest nature is being burnt in vast quantities in America, so that any national deposits of semi-bituminous coal, brown coal, or lignite should be immediately turned to account for the development of industrial heat. In many countries there are vast deposits of such fuel at present almost entirely undeveloped, the extensive working of which would inaugurate a new and valuable mining industry,

and, at the same time, retain money in the country that otherwise would be spent elsewhere.

National Consumption of Coal and Utilisation of Low-grade and Waste Coal.

In some countries, Government control has to be exercised in the granting of supplies of the better qualities of coal, and an annual apportionment of available good clean coal for industrial and railway purposes is made upon the applications received. In India, for instance, the wording of a fuel distributing report clearly shows the keen competition of railway companies to obtain as high a percentage of the first-class coal as possible and that they indent specially for this grade of fuel for their mail train services. With locomotives fitted for burning fuel in pulverised form there would be no necessity to make any such discrimination, and each railway company would be able, no doubt, to draw its fuel supplies from the low-grade coalfields within its own area.

Fuel wastage in England is as great as, if not greater than, in any other country, and, as England is essentially an industrial country, it will be of some interest to consider the values of fuel economy that could be readily introduced.

The official figures for coal raised to the surface in England for all purposes—bunker coal, exported coal, coal for industrial and domestic uses, etc.—for the years 1903, 1913, 1917, and 1921 are reproduced hereunder :—

1903.

	Tons.	Value.
Total output of mines	230,334,469	£115,167,234 @ 10/- per ton.
Reserved for home consumption . . .	116,529,120	£58,264,560 @ 10/- per ton.

1913.

	Tons.	Value.
Total output of mines	287,430,473	£143,715,236 @ 10/- per ton.
Reserved for home consumption . . .	189,092,369	£94,546,184 @ 10/- per ton.

1917.

	Tons.	Value.
Total output of mines	248,499,240	£372,748,860 @ 30/- per ton.
Reserved for home consumption . . .	199,770,779	£299,656,168 @ 30/- per ton.

1921 (approximately).

	Tons.	Value.
Total output of mines	250,000,000	£375,000,000 @ 30/- per ton.
Reserved for home consumption . . .	167,500,000	£251,250,000 @ 30/- per ton.

A subdivision of coal requirements for various industries and for general use, based upon figures officially estimated for the years 1903 and 1913, are given below, and in order to consider fuel consumption under normal world trading conditions it will suffice to base calculations and comparisons upon the tonnage of coal consumed, say, in the year 1913, but to substitute the increased cost of coal to-day (30*s.*) for the price of coal in 1913 (10*s.*).

Subdivision of Coal for Home Consumption.

	1913.	1921.
	Consumption. Tons.	Value @ 30*s.*
(*a*) Railways	15,000,000	£22,500,000
(*b*) Coasting steamers (bunkers)	2,500,000	3,750,000
(*c*) Factories	60,000,000	90,000,000
(*d*) Mines	20,500,000	30,750,000
(*e*) Iron and steel industries	31,000,000	46,500,000
(*f*) Other metals and minerals	1,250,000	1,875,000
(*g*) Brick works, potteries, glass works and chemical works	5,750,000	8,625,000
(*h*) Gas works	18,000,000	27,000,000
(*k*) Domestic	35,000,000	52,500,000
Total for home consumption	189,000,000	£283,500,000
1913 value @ 10/-	£94,500,000	

If, and it seems only reasonable to suppose that such will be the case, the cost of fuel for many years will be in the neighbourhood of three times the value of coal prior to 1913, the annual bill for home consumption of coal will be in the neighbourhood of £300,000,000, instead of considerably under £100,000,000, as in 1903 or 1913.

This increase has been brought about by a general rise in wages to a level commensurate with humanitarian principles, and will never be much reduced so long as the costs of machinery, fuel, and transport remain at the high figures of to-day. It is to be devoutly hoped that the low standard of wages existing prior to the war will not return; therefore, cost of machinery and commodities must remain at a correspondingly higher level so long as other economies are not introduced.

The only manner in which wage rates can be reduced with equity is to lower the cost of production of metal, machinery, and the cost of transportation, and, consequently, the national index value of food. This can be accomplished, and will be effected only by the most stringent adherence to strict scientific uses of fuel.

By the use of coal in pulverised form, it would not be a difficult matter to effect an all-round reduction of at least 20 % on the total fuel used under the headings: (*a*) Railways; (*c*) Factories; (*e*) Iron and steel industries; (*f*) Other metals and minerals. The collective requirements for these purposes account for 107,250,000 tons of coal. A 20 % reduction would mean the saving of 21,450,000 tons, which, at 30*s*. per ton, would reduce the cost of production on fuel account alone by £32,175,000.

Further, it is stated officially that some 18,000,000 to 20,000,000 tons of coal are used every year in England at the mines. Allowing for the free distribution of house coal to miners, perhaps amounting to 10,000,000 tons, much of the 10,000,000 tons balance of high value coal used under boilers, etc., at the mines could be replaced by the daily wastage of refuse fuel at present tipped on to the dumps. Pulverisation of waste coal for boiler fuel at the mines should render it possible to divert the 10,000,000 tons of standard grade coal to the export trade. Coal used at the mines moreover is very often debited to mining operations at below market value, say, 10*s*. per ton, instead of at market value, 30*s*. per ton. This coal should be made available for sale at market price, and only waste coal used at the mines.

To this 10,000,000 tons of coal set free at the mines can be added the 21,450,000 tons that could be conserved by using fuel in pulverised form for industrial purposes. Thus, a total quantity of 31,450,000 tons would then be available for export.

The intrinsic value of fuel saved in industry, viz. £32,175,000, is, perhaps, not of such great importance as the indirect results of burning fuel in pulverised form. For by cutting down the demand for coal, the cost of local handling, the wear and tear of coal haulage locomotives and rolling stock, and demurrage on trucks would be reduced, and, by burning fuel in pulverised form, metal losses in furnaces would be considerably less than they are, and the collective output of melting and reheating furnaces and of steam boilers would be greatly increased. All these indirect benefits tend towards a better return for capital expended upon plant, and may well prove to be mueh in excess of the actual value of coal saved.

Apart from the conservation of fuel for posterity, these few notes may suggest possible methods of lowering costs of production, and general expenditure, in any coal-producing or coal-importing country, to the direct benefit of the present generation.

The total approximate cost of plant that would be required to effect these savings was mentioned by the author at the Iron and Steel Institute meeting in 1918, and this estimate is reproduced in the following table. The figures are based upon 1918 costs of coal, material, and labour.

	Actual Consumption, 1903.	Proportion of Total Amount for which Pulverised Coal might be Used.	See Note.	Raw Coal. Present Consumption Equivalent.	All-round Reduction by Use of Pulverised Coal.	Net Saving of Coal.	Raw Coal. Reduced Consumption in Pulverised Form.	Cost Figures for Powdered Coal Plant, Conveyor System, Burners, etc.
	Tons.			Tons	Per cent.	Tons.	Tons.	
Railways . . .	15,000,000	40–50 per cent.,	A	6,500,000	40	2,400,000	4,100,000	On a basis of £25,000 for mill-house building and machinery, transport, equipment, and burning apparatus for 100 tons per 24 hours, the cost of pulverised coal plant for 33,000,000 tons per annum would be (for 300 working days) approximately £27,500,000. Interest (at 6 per cent.). Depreciation (at 10 per cent.) on investment = £4,400,000. Maintenance of mill-house machinery and all equipment on American basis 5 cents per ton in mill, and 5 cents per ton on equipment = £687,500. Labour at 9 men per day on 3 shifts for 100 tons per 24 hours at £3 per week per man and payment on 52 weeks = £1,544,400. Dryer fuel and dusting loss at 5 per cent. on 33,000,000 tons of coal at 30*s*. per ton = £2,475,000. Power for milling, conveying, and burning at 30 kilowatt-hours per ton overall cost of electric power at ½*d*. per unit = £2,062,500. Total cost for preparing and burning coal in pulverised form = £11,100,000 (say £11,000,000). Overall cost per ton of coal burned in powdered form = 6*s*. 8*d*.
Coasting steamers .	2,000,000	not feasible at present	B	—	—	—	—	
Factories	53,000,000	Say 30 per cent.	C	15,900,000	20	3,180,000	12,720,000	
Mines	18,000,000	,, 50 ,, ,,	D	9,000,000	30	2,700,000	6,300,000	
Iron and steel industries	28,000,000	,, 30 ,, ,,	E	8,400,000	20	1,680,000	6,720,000	
Other metals and minerals . . .	1,000,000	,, 40 ,, ,,	F	400,000	20	80,000	320,000	
Brick works, potteries, glass works and chemical works .	5,000,000	,, 25 ,, ,,	G	1,250,000	30	375,000	875,000	
Gas works . . .	15,000,000	—	—	—	—	—	—	
Domestic . . .	32,000,000	,, 10 ,, ,,	H	3,200,000	50	1,600,000	1,600,000	
		Totals . .		44,650,000			32,635,000	
		Total annual saving in coal by use in pulverised form				11,615,000		
		Total value of coal saving at 30*s*. per ton .				£17,422,500		
		Cost of pulverising and burning . .				£11,000,000		
		Net annual saving *				£6,422,500		
		Cost of plant and equipment . . .				£27,500,000		
		*Exclusive economy effected in labour costs, loss of metal, etc., etc.						

A. Making allowance for existing electrified lines.
B. Pulverised coal may eventually be used for coasting steamers, either bunkered in powdered form, pulverised on board, or used in colloidal state with crude oil.
C. Assuming that 75 per cent. of the estimated total consumption is used for steam-raising and heating processes.
D. Assuming that the estimated total consumption is for coal used for power and haulage and does not include coal distributed to miners and used for domestic purposes. Usage of coal for heating and subsidiary purposes at the mines may account for a considerable quantity of this total coal used.
E. Coal in pulverised form could undoubtedly be applied very extensively in the iron and steel industries, leaving out of account blast-furnaces and gas-fired open-hearth melting furnaces.
F. For copper smelting powdered coal has replaced other fuels in the States. It could also be used to advantage in the melting and annealing of brass and other alloys.
G. Powdered coal is very suitable for firing kilns and for glass-melting, especially where hand-fired coal or oil fuel firing are now employed.
H. This would only apply to central heating systems for offices, hotels, and institutions, for which purposes pulverised coal would be delivered daily by a Central Supply Company.

It has been explained that in a country, such as the United States of America, where coal supplies are abundant and, therefore, cheap—in the neighbourhood of 6*s*. or 8*s*. per ton, as a rule—there is no such incentive to instal costly pulverising plant, except for purposes where other advantages, apart from the economical use of fuel, are of primary importance. Yet, in America, this system has become well established, and very widely adopted.

The cost price of fuel has a decided bearing upon the question of capital outlay for pulverised coal plant and equipment. This can readily be understood by reference to the price of slack or small coal in England during the past few years —the average rise in price being given in the following table, in which values are also given for a one-third saving in fuel consumption, the annual value of such a saving, and the capital cost for a 250-ton per day pulverised coal plant :—

Industrial Coal. Actual Rise in Price (delivered).	A One-third Saving would equal.	Total Operating Costs per ton (Interest and Depreciation, etc. included.)	Total Operating Cost in per cent. of Coal Price.	Value of Net Saving in Fuel Alone. Per Day.	Value of Net Saving in Fuel Alone. Per Annum.	Approximate Cost of Plant and Works Equipment.
s. *d.*	*s.* *d.*	*s.* *d.*		£ *s.* *d.*	£ *s.* *d.*	
1903 . . 7 6 per ton	2 6	2 0	26·6%	6 5 0	1,875 0 0	£18,000 (1903–1913)
1913 . . 13 0 „ „	4 4	2 6	19·2%	22 18 4	6,875 0 0	
1918 . . 25 0 „ „	8 4	3 10	15·0%	56 5 0	16,875 0 0	£30,000 (1918–1920)
1919 . . 30 0 „ „	10 0	4 3	14·1%	71 17 6	21,562 10 0	
1920 . . 36 0 „ „	12 0	4 9	13·2%	90 12 6	27,187 10 0	

[*Note.*—The figures are based upon a plant capacity of 250 tons of pulverised coal per twenty-four hours and three hundred working days per annum. At the lower prices for coal the £18,000 expenditure on plant may appear excessive, but at the higher prices for coal the annual savings to be effected almost equal the higher cost of plant.]

Distillation of Coal.

In the foregoing, the only question considered has been the means of satisfying a portion of general fuel requirements by the more economical method of applying fuel in pulverised form. It is quite conceivable that a greater national asset would be introduced where fuel supplies are of the nature of bituminous coal, lignite, peat, etc., which contain considerable quantities of volatile and other valuable constituents, if distillation processes are worked for the recovery of these lighter hydrocarbons and fertiliser materials, and the commercial value of motor spirit, light and heavy oils, lubricants, tars, ammonia and nitrogen products, coal tar dyes, etc., is realised. After recovery of these oil fractions and chemicals, the coke residue can then be pulverised. When coalfields consist of anthracite, or other low volatility fuel, it naturally would not pay to resort to distillation. In any case, when coal is of a volatile nature, the commercial value of the lighter hydrocarbons and chemicals should be obtained by careful analysis before a decision is taken to burn the virgin fuel to complete combustion. In some countries it will pay to erect plant for the

purpose of oil recovery, but, in others, nearer to the sources of natural oil supplies, it would be a mistake to pass coal through any distillation process.

Market values must be the guiding factors in each and every country. The approximate yields of motor spirit, oil, and sulphate of ammonia are given below and referred to again at p. 132.

From a study of these figures, and by applying them to any given quantity of annual tonnage of coal suitable for distillation, an approximate idea of the value of the constituents of the fuel can be ascertained. If, for instance, it were possible to treat one-half the 250 million tons, which is the quantity of coal annually mined in England, there could be obtained, therefrom :—

Smokeless coke	say, 70 %	87,500,000 tons.
Crude tar (to be used as liquid fuel)	„ 3·5 %	4,375,000 „
Crude benzol	„ 1·0 %	1,250,000 „
Refined benzol	„ 0·5 %	625,000 „
Ammonium sulphate	„ 1·25 %	1,562,000 „

The coke produced from the distillation of 125 million tons of suitable coal would thus realise half the quantity of solid fuel required within the country for industrial and domestic purposes, which, as previously stated, is about 167 million tons. This could be burned as a straight smokeless fuel, or in conjunction with the supplies of anthracite and low volatile coal (which would not be subjected to distillation), making up the total amount necessary for industrial and domestic use.

The $4\frac{1}{2}$ million tons or so of crude tar could be used as liquid fuel, replacing 6 or 7 million tons of solid fuel, or again split up into its numerous chemical constituents.

It may be contended that it is dangerous, or at least inadvisable, to make such wide statements on this subject, but it is necessary to do so if the possible limits of economy and recovery of valuable products are to be considered in relation to the future prosperity of the industrial life of any nation possessing solid fuel deposits.

All these considerations are collectively of national moment, and in further substantiation of the colossal wastage of the constituents of solid fuel when burned under the inefficient conditions of to-day the following total values given in a paper by George Hunter, which he read in 1919 before the Past and Present Mining Students' Association at the Wigan (England) Mining and Technical College, are instructive.

" If we take the 35,000,000 tons of coal used for domestic purposes annually we find that there passes up the chimney in the form of soot and deleterious gases : 105,000,000 galls. of motor spirit; 175,000,000 galls. of illuminating and fuel oils; 245,000,000 galls. of heavy lubricating oils; 990,000 tons of pitch; and 1,400,000 tons of sulphate of ammonia. The approximate value of these wasted constituents of the coal is about £64,000,000 per annum. If we take the 80,000,000 tons of coal used for power generation we are sending uselessly into the air : 240,000,000 galls. of motor spirit; 400,000,000 galls. of illuminating and fuel oils; 560,000,000 galls.

of heavy lubricating oils; 2,000,000 tons of pitch; and 3,200,000 tons of sulphate of ammonia. The approximate value wasted in this case amounts to £90,000,000 each year. Thus the waste from these sources alone represents a loss of about £154,000,000 every year."

Incidental Claims for Utilisation of Pulverised Fuel.

In addition to the value of the fuel saving, one must study the many other advantages that can often be realised by burning fuel in pulverised form. These can be briefly enumerated for various applications as follows :—

National Considerations

Conservation of fuel resources by 20–50 % per annum, or, conversely, increased output for present quantities of fuel consumed.

The addition of low-grade fuels, dust, mine heaps, lignites, brown coals, peats, to national supplies, thus saving high-class coal for bunkering and export.

The transference of unskilled labour in works and factories to more profitable occupations.

The lowering of production costs, which, together with increased output, will enable home prices to compare favourably with competitive foreign prices.

The betterment of working conditions.

Power-House Boiler Plants

Economy in fuel, and possibility of using local inexpensive coal, anthracite and bituminous smalls and dust.

Increased steaming rates for boilers.

Elimination of hand-firing conditions and expense.

Elimination of mechanical stoker maintenance costs.

Smokeless operation.

No banking losses.

Small loss of steam pressure over lengthy periods of shut down.

Quick steaming for peak load periods.

Clean boiler tubes and heating surfaces.

Iron and Steel Industries

Considerable reduction in fuel consumption.

Increased output of furnaces.

Reduction of labour.

Metal losses reduced.

High or low temperatures maintained constant.

Higher furnace temperatures obtained, with or without regeneration or recuperation, than by any other means of firing solid fuel.

The possibility of using cheaper grades of local, so-called waste, fuels for many purposes in place of expensive high-class coal.

Marine Purposes (Suggested)

Increased steaming radius of ships.

Stoke-hold conditions as for oil firing.

No coal trimming required.

Personnel reduced.

Increased cargo space.

No smoke.

Bunkering in port or at sea as for taking in oil, or direct pulverisation on board ship.

Clean boiler surfaces and increased steaming rates for boilers.

Full steam raised almost at a moment's notice.

No banking losses on short calls.

Locomotives

Elimination of smoke.

No sparks or cinders which may cause fires.

No firing tools, netting, or spark arrestors.

Superheaters unit always clean.

Clean boiler tubes.

Increased mileage of engines.

Reduced back pressure on cylinders giving increased tractive power of loco.

The use of all or any local fuel in lieu of expensive, often imported, high-class coal.

Firebox strains reduced, and leaky tube joints avoided.

No banking losses.

Little loss of pressure over lengthy periods of "off duty."

Coal supplies concentrated at a few points only, and no wastage from engine tenders.

No fuel consumed whilst standing or drifting.

The advantages mentioned above are of as much importance from a national economy point of view as they are to individual owners of works, or to the shareholders of companies.

When it becomes an impossibility to extend steam-raising plant, or furnace capacity, for instance, owing to the circumscribed area of a factory premises, or when the fuel available contains so much ash that wear and tear of fire bars, low steaming of boilers, and cost of labour for hand firing and removal of clinker become serious considerations, it will often be found possible to overcome these and other difficulties by adopting either oil firing or pulverised coal firing.

Inferior grades of coal which one may be forced to purchase can be burnt under conditions which will often render existing boiler plant of ample capacity to meet increasing demand for steam in a works that has outgrown the steaming rate of boilers when hand or stoker fired.

Boilers provided with combustion chambers of sufficient area adequately to

effect the complete burning of any pulverised coal can be run at two or even three times the maker's rating, thus providing additional boiler duty without putting in further plant.

Another obstacle sometimes confronting a works engineer is the inadequacy of existing boiler flues to carry away with sufficient rapidity the large volume of products of combustion when a heavy quantity of air or steam is forced through fuel on the grates in order to burn the combustible matter contained in inferior coal. By the substitution of pulverised coal firing for hand or stoker firing under such conditions, the volume of waste gases in the flues is greatly diminished. An actual estimate of the relative quantities or volumes under various conditions can be made by use of the formula on p. 94.

From a reference to this table of volumes it will be readily seen that when only 20 % excess air is present, as in pulverised coal firing, instead of the 200 % or 300 % for hand or stoker firing, existing flues and stacks can be made either to accommodate additional boiler plant, or the burning of larger quantities of fuel to raise additional steam, without any alteration to the main flues or chimney.

It may be argued that the use of mechanical stokers would in a measure reduce fuel consumption as compared with hand firing, and that, at the same time, the steaming of boilers would be increased. To a certain extent this argument holds good, but it frequently happens that boilers are placed so close together that the necessary provision of side inspection, and clinker handling holes usually required when stokers are run at high duty with inferior fuel, cannot be made. If this is so, then stokers cannot be run at much above the normal rating for the boiler. Under pulverised fuel-firing conditions inaccessibility for breaking up clinker formation on grate bars does not enter into the question, the ash thrown down in the combustion chamber being easily removable.

Much harm is very often done by advocates of pulverised coal firing when they maintain that this system should, in all instances, be adopted in substitution for existing mechanical stoker equipment. When boilers are fitted with up-to-date mechanical stokers, and are operated under trained supervision, and with fuel of sufficiently good quality to prevent undue clinker troubles, a boiler and furnace efficiency of 75 % or so is obtainable for continuous firing. Pulverised coal firing will not effect an improvement on these results at or about normal rating of boilers. Furthermore, mechanical handling of the coal from the point of delivery to the stoker supply bunkers presents no great scope for any further reduction of labour. The improvement in boiler and furnace efficiency of 4 % or 5 % which might be made under pulverised fuel-firing conditions would not offset the extra cost of fuel preparation, much less compensate for the heavy capital outlay upon coal drying and milling plant that would replace the stoker equipment. In such cases the relatively inexpensive, though less efficient, self-contained pulverised coal unit would be the only alternative apparatus to consider.

What can be accomplished by way of improvement upon working costs lies more in the purchase of lower grade and, therefore, lower priced fuel, often available, of approximately equal calorific value to that required for maintaining a high degree of efficiency with stoker firing. By a substantial reduction in the annual fuel bill

to show a sufficient margin to cover the cost of changing over to pulverised coal firing, the advantages of that method, viz. increased steaming rate of boilers with a corresponding reduction of the number under steam, can then be realised.

It is, however, quite another question when new boiler plant is under consideration, for with pulverised coal firing a cheap grade of coal can be purchased at the outset, perhaps but half the number of boilers will be sufficient as against mechanical stoker firing, and one-third the number as for hand firing; labour also will be proportionately reduced.

The smaller ground area required for pulverised coal-fired boiler plant, the reduced sectional area of flues, and smaller diameter and height of chimney-stack can all be valued and placed against the cost of preparing the pulverised coal, and of the conveying and burning equipment.

It has been proved time and again that for a new boiler-house the capital outlay upon mechanical stoker equipment, boiler-house bunkers, belt conveyor, elevators, etc., is approximately equal to, if not slightly in excess of, complete pulverised coal preparation plant, building, fuel transport system, boiler bins, feeders and burners. For all intents and purposes the cost of both systems for plants of fair size can be taken as being equal. Conclusive data on this point are given in Chap. X wherein the capital outlay for hand firing, stoker firing and pulverised coal equipment is discussed in greater detail.

Concentration of Coal Supplies.

In a works extending over a wide area the concentration of fuel supplies at one point is a matter of considerable importance. The preparation and conveying of fuel in pulverised form render this a possibility where supply has to be made over a radius of 1000 yards or so. For works extending over a narrow but long strip of land it will no doubt be more convenient to provide additional concentration points.

In many works coal is now left in railway trucks alongside the buildings, and must be hauled over the works track to the positions of furnaces and boiler-houses. For this purpose, shunting engines are employed, each carrying perhaps two men. The engines have to be maintained in proper running order, and to be provided with sheds. The works tracks occupy valuable ground space and must be constantly repaired. Besides all this, coal trucks in a works are often in the way of works routine operations, and the presence of rail track is frequently a nuisance.

When a pulverised coal system is introduced, the total fuel supplies can often be delivered at a point outside the works altogether, where the fuel can be pulverised and subsequently transported through ordinary iron pipes to the receiving bins at the furnaces or boilers. Thus are eliminated the shunting of locomotives, the wages paid to men for operating them, the obstructions caused by coal trucks, and the space lately occupied by rail track is turned to better uses.

Captain H. C. Armstrong, in a paper read at a meeting of the Joint Association of the Managers and Foremen of John Brown & Co., Ltd., and Thos. Firth and Sons, Ltd. (two of the most important shipbuilding and iron and steel works in Great Britain) referred to the high cost of handling coal throughout a large

works covering a considerable area, and emphasised the very difficult problem of control of rail traffic, for the supply of coal to departments. In America, the whole works are designed *en bloc*, but works in the older countries have grown and have been added to piecemeal, with the result that a great deal of cross-shunting and in-and-out traffic increases the cost of handling coal. The cost of shunting coal, as given by Armstrong for one of the big works belonging to the group referred to, was 2*s*. 7*d*. per ton. Adding to this 10*d*. per ton for carting ashes, and the firemen's and coal-wheelers' wages, the cost of putting the coal into the fire was found to be 14*s*. 9*d*. per ton on the boilers and 18*s*. per ton on the furnaces. This estimate as to the cost of delivering coal and removal of ashes in a large works directly supports the claims advanced for the use of fuel in pulverised form.

In place of traffic disorganisation, due to fuel trains and cross-shunting; the noise, smoke, and upkeep cost of locomotives, trucks, rails, etc.; fuel scattered and dumped in all weathers at the hundred and one points throughout the works; the fuel supplies of pulverised coal would be concentrated at one or two points, and the pulverised coal be forced through delivery pipes. Overall cost of production and supply would not amount to one-half that given by the author of the paper mentioned above, and the resultant saving in fuel consumption, increased output of furnaces, boilers, etc., would, undoubtedly, in many cases, counterbalance the other half of the costs referred to.

Under such conditions a close check can readily be made of coal deliveries, and the quantity of fuel supplied to various departments, every ounce of which will be transported out of sight and with no loss due to windage or truck leakage.

As compared with any other system, producer gas, mechanical stoker, or hand firing, the general reduction of works costs of production due to the introduction of pulverised coal firing must not be lost sight of. The reduction of fuel used often amounts to between 30 % and 50 %.

Then, again, damage sometimes results from the use of coal high in sulphur as a boiler fuel, particularly so when water-tube and fire-tube boilers are installed. For the same reason, high sulphur coal cannot be purchased for various metallurgical purposes, such as for use on open-hearth steel furnaces.

When fuel is burnt in pulverised form, the resultant flame temperature is in the neighbourhood of 1700° to 1800° C., so that the sulphur is completely burned to SO_2, and travels straight through the boiler passes, or over the furnace hearth with the superheated products of combustion. There is no chilling or condensation of sulphur monoxide (SO) upon the boiler tubes, with the resulting destruction of the tubes by sulphuric acid (H_2SO_4).

As a gas-producer fuel, coal which may contain 3 % of sulphur for boiler firing and 1·5 % for open-hearth furnace firing is frequently ruled out because of the sulphur, but, in pulverised form, coal containing respectively 5 % and 3 % of sulphur can be, and is being, used with no detrimental effects. Not only, therefore, does the application of pulverised coal for industrial uses make possible the reduction of fuel consumption and the purchase of lower standards of fuel supplies, but one may safely use higher sulphur coal.

Iron and steel billets, iron more so than steel, when heated in pulverised coal-fired furnaces, absorb to a much greater depth what may be termed a soft, even, penetrating heat with little oxidation of exposed surfaces than is possible when other methods of heating are employed. It has been proved that billets heated in this manner for heavy forge work, as, for instance, propeller shafts, etc., can be worked twice as long under the hammer as when heated in any other manner. In continuous reheating furnaces, the scaling losses on billets have been reduced by 50 % over previous practice with furnaces fired with oil or natural gas.

CHAPTER IV

THE VARIOUS GRADES OF FUEL SUITABLE FOR USE IN PULVERISED FORM

The Burning of Weathered Coal, Inferior Coal, and Dust—Fusibility of Inert Material—Bituminous Coal—Anthracite and Anthracite Culm—Coke—Coke Ashes—Peat, Lignite, and Brown Coal—Cannel Coal—Pitch—Waste Coal—Belt Pickings—Cinder, Smut, or Mother Coal (Fussain)—Washery Sludge—Oil Shale—Indian and Eastern Coal—Classification of Coal in Various Countries—The Drying of Wet Fuel (Peat).

Coal must have a certain minimum content of volatile matter in order that it may ignite freely and that combustion may be maintained. But the range of fuels which can be used in pulverised form is such a very wide one that it almost becomes unnecessary to set any limit.

Weathered Coal, Inferior Coal, and Dust.

Many a grade of fuel cannot be burned on any form of grate on account of physical subdivision into very small particles, as for instance " duff " coal, small slack, coal washings, etc., or disintegrated fuel, such as lignite and cannel coal, when exposed to the " weathering " action of the atmosphere. Some grades of solid fuel will also split up into extremely small particles when placed on a hot fire, and, when this takes place, the fuel is no longer large enough to burn in the ordinary way on grates, and either falls through to the ash pit, or becomes packed in such a dense mass that ordinary draught pressure is insufficient to penetrate the fuel bed. If draught pressure is increased so that the air supply penetrates the fuel on a grate, the whole mass is kept in such a state of agitation, that many of the larger particles tend to drop between the grate bars, and the smaller ones to be carried away into the flues. If, however, we further reduce the size of the particles of the " duff," small, washings, or " weathered " fuel by efficient pulverisation, we can utilise all these grades successfully and at high combustion efficiencies.

Whether it will pay to pulverise the heavy percentage of non-combustible in a coal high in ash, with consequent added wear and tear on the pulveriser, and increased cost for power in relation to the actual heat-producing constituents of the coal powdered, is a question that must be settled according to the price to be paid for the fuel, and the purpose for which it is to be used. That much inferior high ash coal should be washed is clearly proved in Chap. VI, dealing with the Washing of Coal and the making of Colloidal Mixtures.

The successful burning of hard, low volatile anthracite coal, washery sludge, coke breeze, and by-product fuel from distillation plants can all be used for industrial purposes in this manner. Even ash-dumps at the engine-cleaning pits were used

up as boiler fuel during a coal strike on the Missouri, Kansas, and Texas Railway in America, the loco clinker and smoke-box waste being mixed with the available fresh coal, and burned under the boilers as pulverised fuel.

Fusibility of Inert Material.

As success or failure in burning the widely varying grades of solid fuel by ordinary methods depends so largely upon the content and quality of the ash (this has not so great a bearing when the fuel is burned in pulverised form), some notes on this subject will be of interest.

Considering the question of ash from a purely physical point of view, the ruling temperature in a furnace or fire will to a large extent determine the precise degree of trouble that will arise. If the ruling temperature is low, say of the order 900–1000° C., few classes of fuel will be met with containing ash that will present difficulties owing to its fusibility, because, as a rule, fusion will not take place to any extent at this range of temperature. If temperatures of the order 1000–1400° C. are obtained, then there is more possibility of serious trouble with the ash contained in all but the best quality of coals. But if, as in many metallurgical operations, temperatures above 1400–1600° C. are prevalent, it becomes possible in nearly every case to deal with the fused ash in the form of molten slag, and to make arrangements to run off the slag in the usual way without much trouble. On the other hand, owing to chemical combinations at the higher temperatures, the more violent and destructive will be the action of the ash.

When a piece of lump coal of any size down to $\frac{1}{4}$ in. cube or less is placed on a fire supported on any form of grate, the exterior surface of the coal ignites, and, in due course, the whole of the combustible material on the surface is consumed, leaving a coating of ash. If the surrounding temperature is insufficient to fuse this coating of ash, it gradually flakes away and becomes detached, partly due to abrasion and partly to expansion and other agents, thus leaving a further exposed surface of carbon for combustion. In this way, the whole piece of coal will in time become completely consumed, leaving the ash and some of the combustible matter in the form of powder, or, if fused, in the form of clinker. Under such conditions it is practically impossible to obtain complete combustion, although little difficulty may be experienced in dealing with the removal of the ash.

A very different result will be obtained if the temperature of the fire is sufficient to fuse the first coating of ash on to the pieces of coal, as, for instance, with certain classes of Brazilian coal which, upon heating, fuse into a solid mass. In this state it becomes altogether impervious to air, and consequently the interior portion of the fuel remains unconsumed and combustion ceases. Another trouble may be that the particles of ash run together, forming a semi-liquid clinker, which may spread over or ooze through the grate bars, and in any case the air spaces between the latter will become partially or completely blocked; moreover, should the ash contain much iron sulphide it will, when molten, rapidly cut away and destroy iron grate bars.

Many of these known difficulties, such as the cleaning of clinker from grate

bars, semi-fusion of soft coal and ash, patchy firing, blow-holes in fires, etc., are naturally overcome when fuel in a finely divided pulverised state is burned in suspension in air, and entirely out of contact with any other body at the time of its maximum temperature. Each tiny particle of fuel is then completely surrounded by a film of air, combustion is instantaneous, and the ash, denuded of all heat elements, falls out of the active flame zone. This is the reason why fuel containing 30 %, 40 %, and even 60 % of inert material can be burned in this manner with virtually the same furnace combustion efficiency as for low ash fuel. Although, as maintained, 30 % and 40 % ash fuel can be readily and successfully applied in this way, the question arises for consideration of balancing the cost of pulverising and subsequent removal of this bulk of useless material as clinker, against the cost of washing the fuel to a great extent free of ash prior to running it through the mills. This consideration is gone into at greater length in Chap. VI.

J. G. Coutant supplies the following notes on the importance of fusibility of ash in coal as affecting the formation of clinker in combustion chambers of boilers :—

The melting temperature of ash depends on the chemical composition of the ash and on the conditions of heating. The exact effect of each constituent of ash upon the actual melting point has not yet been definitely determined, but it is certain that the nature of combustion conditions to which the ash is subjected to heat has a marked effect on its melting point. It has been observed in many cases where pulverised fuel has been used in connection with boilers, that it is easy to maintain the highest percentage of CO_2 in gases with the proper feeding apparatus and burners, but under certain conditions great difficulty has been experienced with excessive slagging, to such an extent that refractory linings have been partially destroyed, in addition to the difficulty presented as regards the removal of fused ash. This excessive slagging has been attributed in the past to high flame temperatures; this is not strictly correct, because at any temperature obtained slagging can be avoided by proper air regulation.

Further consideration of this question has established the fact that if the ash is heated in an oxidising atmosphere its melting point is higher than if the ash is subjected to high temperatures in a reducing atmosphere. The difference between the melting points in an oxidising and in a reducing atmosphere is upwards of 140° C. (261° F.) for certain grades of coal.

The table on p. 42 gives the analyses and melting points of three samples of ashes as determined by Messrs. A. G. Fildner and A. E. Hall (Bureau of Mines, Washington, U.S.A.).

This brief review of the properties of ash will make it quite clear that the wide range of fuel mentioned hereunder can be readily applied in pulverised form.

Bituminous Coal.

There is no bituminous coal which cannot be burned in pulverised form. The ash content will be the determining feature as to whether a certain coal is to be recommended for any specific purpose, but, broadly speaking, any bituminous coal with an ash content up to 30 % or even 40 % can very well

Effect of Oxidising and Reducing Atmosphere on the Fusion Point of Ash.

Silica (SiO_2), %	54·76	42·23	47·29
Iron Oxide (Fe_2O_3), %	6·85	19·03	9·84
Alumina (Al_2O_3), %	29·23	30·55	34·59
Titanium Oxide (TiO_2), %	1·80	1·23	1·80
Lime (CaO), %	1·41	1·28	1·24
Magnesia (MgO), %	·64	1·06	·41
Sulphur Trioxide (SO_3), %	·96	20	·06
Potash (K_2O), %	2·09	2·94	2·45
Soda (Na_2O), %	1·87	1·33	2·13
Fusion Temperature in oxidising atmosphere	°F. 2642 °C. 1456	2642 1450	2489 1365
Fusion Temperature in reducing atmosphere	°F. 2509 °C. 1376	2606 1430	2395 1313
Difference	°F. 133	36	94
Kind of Coal	Pocahontas	Mingo Bed, Claiborne, County Tenn.	Coal Creek Bed, Anderson, County Tenn.

be burned in this manner under suitable conditions, with a loss of but 0·5 % of the combustible matter.

Anthracite and Anthracite Culm.

Difficulty is experienced in burning anthracite coal in combustion chambers of insufficient volume. For the smaller sizes of furnaces, and for locomotives, it may beeome necessary to mix with the anthracite a certain percentage of bituminous coal, owing to the limited area of the combustion chamber, and the absence of any large body of hot refractory brickwork.

At the 1917 Convention of the American International Railway Fuel Association, in the report of the Powdered Coal Committee, it is stated that :—

" The average annual output of the anthracite coalfields of Pennsylvania, for the five-year period ending December 31, 1915, was practically 70,000,000 tons. About 8 % of this total output can be considered as waste, it being of such a nature that its satisfactory combustion, either in hand- or stoker-fired furnaces, is not possible. This waste culm or slush has the following general characteristics :—

Average Size

2 % through 5/16 round mesh and over 3/16.
8 % through 3/16 round mesh and over 1/16.
90 % through 1/16 round mesh.

Average Analysis—Dry

Ash	24·00	per cent.
Volatile Combustible	6·00	,,
Fixed Carbon	70·00	,,
	100·00	,,
B.Th.U.	11,500	

"The raw slush before drying will contain from 8 to 30 % (and sometimes more) moisture. It can be seen from the above that this is not a very attractive fuel for ordinary firing methods and burning on grates.

"The utilisation of this culm in pulverised form is, however, possible and practicable, and has been in use at a colliery in the Scranton district of Pennsylvania for about two years. Drying, pulverisation and handling are accomplished in the usual manner, the product averaging about 94 % through a 100-mesh screen and 86 % through a 200-mesh. No difficulty is experienced in handling, but the wear on the type of pulveriser in use is somewhat higher than when straight bituminous is being worked."

Further tests carried out at the anthracite collieries in the Susquehanna district in burning washery slush were so successful that the whole boiler plant at the anthracite collieries at Lykens and at Lytle has been arranged for burning this grade of "waste" fuel in pulverised form.

Coke.

Gasworks coke or coke breeze containing, say, 8 to 10 % of volatile combustible matter is by no means unsuitable for use in pulverised form. If such coke should contain less than 5 % of volatile combustible matter, the deficiency in this direction can very easily be made up by the admixture of coal rich in volatile combustible prior to pulverisation of the two.

At the Bethlehem Steel Company's works at Lebanon, an ore-roasting furnace has been fired with pulverised coke containing only $1\frac{1}{2}$ % of volatile matter. Although it is evidently possible to fire a roasting furnace with fuel containing this small amount of volatile matter, it is doubtful, even with very fine pulverisation, whether this would be satisfactory for boiler firing, without mixing with the coke 20 % or so of higher volatile bituminous coal.

In a paper by S. W. Parr and C. K. Francis on "The Modification of Illinois Coal by Low Temperature Distillation," the authors state in reference to the residue coke : "While much of the volatile constituent remains, it has undergone a change which makes it not difficult to carry on combustion without the production of smoke," and "Because of the very great ease with which this material may be broken down it would require, in all probability, to be subjected to the briquetting process."

The chief difficulty to be encountered in the pulverisation of coke breeze is the excessive wear and tear of the pulverising mills when the coke is of a hard nature. The authors quoted, however, suggest that the residue coke from the low temperature carbonising retorts can be maintained in such form that the material can be readily broken down. The fuel then becomes a valuable asset in this treatment of coal, the coke being a smokeless fuel of high carbon content.

Low temperature distillation processes should be so regulated that the coke produced shall contain say 8 % or 10 % of volatile matter, and be of friable nature. In this respect, the subsequent burning of the pulverised coke will become an asset to the distillation process by removal of one of the objections to the

latter, viz. the accumulation of by-product coke in such quantity that the disposal of it presents a serious difficulty.

Subsequent to the extraction of 8 % by weight of Kent coal, for instance, as liquid fuel, or some 18 galls. per ton by means of the Freeman low temperature process, a valuable and readily pulverisable coke is produced having an analysis of approximately 8 % volatile matter, 80 % fixed carbon, and 12 % ash.

Coke Ashes.

Another form of waste fuel which can be used with advantage to augment the supplies of fuel suitable for pulverisation is the smalls or "ashes" screened from metallurgical coke at the ovens. This may be somewhat hard and produce heavy wear on pulveriser mill parts, but this is not always the case, since some coke ashes are readily reducible without excessive mill wear. Coke ashes approximate to 4 % moisture, 25 % ash, and 75 % combustible matter.

Peat, Lignite, and Brown Coal.

The following notes are based on a translation of information supplied by A. B. Helbig.

The problem of artificial drying, or the mechanical dehydration of peat, lignite, and brown coal, has not yet been satisfactorily solved, so that the utilisation of peat in particular has been confined more or less to districts where climatic conditions ensure an annually recurring period of warm, dry air, as, for instance, in Russia, Finland, or Italy, during which peat can be dried naturally. Mechanical peat cutting or pumping, automatic stacking or drainage, and disposal of the air-dried sods is an industrial trade in such countries. Distillation plants will be the means of extending the use of this class of fuel in other spheres, more especially when better mechanical facilities are evolved for extracting the 30 to 90 % of excess moisture. In order to use peat in pulverised form it is necessary first to tear the structure apart, and to pass the shredded peat through steam- or gas-heated dryers.

The chief difficulty in the treatment of peat for rendering it suitable for pulverisation lies in this heavy content of moisture which must be driven off before it can be properly powdered. Peat is usually dried to about 20 % of total moisture for efficient burning in powdered form.

Without doubt, the development of scientific investigation in the direction of peat utilisation in the form of pulverised fuel will disclose valuable industrial possibilities in the near future.

Much work in this field has been accomplished by the American Peat Society, and certain useful progress is recorded in the *Journal* of that Society published in January, 1921, which gives, briefly, results obtained with peat mined by the Hennepin Atomised Fuel Co., of Minneapolis, and pulverised at the engineering department of the University of Minnesota.

Under the old hand-firing conditions, 5 to 6½ lb. of water were converted into steam per lb. of coal, whereas with pulverised peat the evaporation per lb. of fuel fired was 9·9 lb. It was also proved that the pulverised peat gave approximately

90 per cent. of the effieiency obtained with pulverised coal; 105 lb. of pulverised peat equalling 96 lb. of pulverised coal.

The State Department estimate that there is a local supply of 6,558,000,000 tons of peat, or enough to last one thousand years at the present rate of industrial consumption.

Peat mixed with bituminous coal has been used in powdered form in locomotives on Swedish State Railways. See p. 358.

A. B. Helbig points out that it is in itself decidedly uneconomical to pulverise and burn the dried brown coal or peat as such, seeing that it involves the loss of the valuable volatile constituents in which these two fuels are especially rich. The more correct proceeding (as the author of this book has always contended) is to carbonise them at low temperature and to burn the low temperature coke. The advantages gained by this method of using such fuel are: (1) The volatile constituents are saved in the form of oil and gases of high value. (2) The low temperature coke is not explosive or inflammable, nor, like dried peat and brown coal, liable to spontaneous combustion. (3) It can, therefore, be sent by rail, which is not admissible with peat, lignite, and brown coal when dried; and when in a damp state, rail transport is too costly. (4) Weight for weight, the power required for pulverising low temperature coke is about one-third the power expended in pulverising the dried raw material, and the cost of the upkeep of the mill diminishes as pulverisation improves. In reckoning the value of the coking process, the market value of the by-products is obviously a factor to be taken into account. The recovery of the phenols is said to have been recently achieved, but whether on a paying basis or not is still uncertain. It has not yet been practically decided whether gasification should be carried out in stationary or in rotary retorts. It is Helbig's opinion that for treating brown coal and peat on a large scale the only method is rotary kiln gasification, by which method all sizes of fuel down to dust can be treated, so that before being fed into the rotary retort any fuel can be broken to the degree of fineness established by practical working. In the case of fibrous fuel, peat, and brown coal, disintegration is best accomplished by shredding. The ideal starting point for the preparation of pulverised fuel is the low temperature coke of any combustible, and especially that of peat and brown coal. Retorting renders the distillation residue brittle and friable, clean, and easy to pulverise. The distillation of both materials can be carried as far as is desired. The smaller the quantity of volatile constituents in the low temperature coke the finer it must be subsequently pulverised. Given the requisite degree of fineness, even hard coke, whether gas coke or smelting coke, will burn completely. Whether in pulverised or in lump form there is no objection to transporting low temperature coke to any distance, so that the factory using it need not be situated close to the store of raw material. During transit, which should, of course, be in closed trucks, the low temperature coke will absorb but little moisture from the air.

The German Courts have upheld a decision in favour of a patentee whose specification covers the use of a by-product coke as a pulverised fuel. The nature of the patent is not known to the author, but the use of this fuel in this

form surely cannot differ in principle from the use of gas retort coke as pulverised fuel, which has been known practice for many years.

The above notes have been taken from a translation of one of several papers written on this subject by A. B. Helbig, who refers also to Herr von Feilitzer's "Locomotive Firing with Peat Dust" and to Dr. Munzinger's treatise on the "Introduction of Coal Dust as Fuel on a Large Scale."

Brown coal used in a central German cement factory is dried by gas. It is then ground in tubular mills, and the fuel used for firing the rotary cement kilns. Contrary to expectation, ready ignition and combustion, such as one would naturally look for with a fuel of high volatile content, was not at first achieved, many difficulties having to be overcome before the results were satisfactory. Early attempts proved that the degree of fineness was the chief cause of the poor results and that fine pulverisation is as essential for brown coal as for the harder and lower volatile classes of coal. This conclusion will have to be recognised in other German circles, where those interested in the coal-dust question are again making attempts to burn damp, coarse coal dust. Fruitless experiments of this kind made so often in the past only mean further waste of money.

Lignite in its natural state contains a heavy proportion of moisture, but it is being successfully dried and used in pulverised form for many purposes, including the firing of railway locomotives.

It is advisable not to dry lignite below 5 % moisture, otherwise the hydrogen and light gases in the fuel will escape to the stack before their combustion can take place in the furnace. While raw lignite as mined can be burned on grates when used fresh after delivery, this fuel rapidly disintegrates and becomes a mere heap of fine dust when exposed for any length of time to the weather. In the disintegrated state, it can neither be burned on mechanical stokers nor upon hand-fired grates, and, moreover, is useless as a fuel for gas producers. For the purpose of burning in pulverised form, it matters nothing whether the fuel has been freshly delivered or reduced to a state of dust by weather. At the lignite mines great care is generally exercised to prevent breaking up the lumps, and all the smalls are left in or at the mine; the amount of dust and small useless fuel is often as much as 20 % of the total quantity mined. All this waste can be turned to good account when dried and pulverised.

Lignite is generally soft and readily ground, so that mill output is increased above the standard rates for grinding anthracite or bituminous coal. In consequence of increased output, the power per ton ground is correspondingly reduced; on the other hand, the heavy moisture content reduces the capacity of dryers. Lignite is an excellent fuel for metallurgical work where sulphur contamination may be detrimental to the process, for, as a rule, it contains little or no sulphur. The quantity of ash in lignite may be considerable, but as this may be more or less infusible, it is as a rule easily removed from furnace combustion chambers or flues in a dry or powdery form. Lignite ash may present some trouble as "honeycomb" on tube sheets of locomotives. This matter is referred to at p. 348.

The following is an account by W. H. Maddocks, of the Missouri, Kansas and

Texas Railway, U.S.A., regarding the first tests ever made with powdered lignite for firing water-tube boilers.

"Hoyt, Texas, lignite as tested gave the following analysis :—

	Wet %.	Dry %.
Moisture	24·48	7·06
Volatile	38·17	54·52
Carbon	28·94	24·72
Ash	8·41	13·70
	100·00	100·00
Sulphur separately determined	0·53	0·098
B.Th.U.	7996	10,675

"Five car-loads of this coal have been used under various conditions. Two of them had been exposed to heavy rains and showed 46 % moisture. With our limited dryer capacity the coal was repassed, and, when finally used, showed moisture varying from 7 to 18 %. Coal burned under these conditions gave good results, no slag, and, under high forcing of the furnace, an evaporation of 7·33 to 8·8 lb., from and at 212°, per lb. has been obtained with this low B.Th.U. value. No choking of screens occurred in milling at this moisture content, but it is believed that the limit was about reached.

"The average fineness was 93 to 94 % through 100-mesh and 84 to 86% through 200-mesh screen; this, with a moisture of 7 %, not quite so good with 13 % moisture. Quantity milled was in excess of bituminous coal. One car was unloaded in November, 1916, and the coal was stocked and used the following summer. This was dried, milled and used with no appreciable loss.

"With a dryer designed for this coal with its excess of moisture it could be burned equally as well as bituminous and with less deterioration on furnace refractories due to non-slagging."

That lignite in pulverised form can be used with advantage for firing steam boilers has since been further demonstrated by the following test taken at one of the large meat-packing works in America.

Boiler Test with Pulverised Lignite as recorded by Engineers of Swift & Co., U.S.A.

Duration of Test—9 hrs. 58 mins.

Boiler.	
1. Type	Water-tube.
2. Heating surface	4960.
Furnace.	
3. Volume	1485.
4. Ratio of furnace volume to water-heating surface	113·34.
5. Method of combustion	Lopulco System pulverised fuel.
Coal.	
6. Kind of coal	Lignite.
7. From	Mine at Hoyt, Texas.
8. Car	M.K. & T. 30813.
9. Size and condition	Run-of-mine.

10. Weight of coal as received	42·327.
11. Speed of feeder screw	116·3 r.p.m.
12. B.Th.U. per lb. of coal as received	6722.
13. B.Th.U. per lb. of coal as fired	7928.
14. Coal consumed per hour	4246·8.
15. Coal delivered per screw revolution	·3004.
Analysis of Coal as Received.	
16. *a.* Fixed carbon	31·36.
b. Volatile matter	23·71.
c. Moisture	33·13.
d. Ash	11·80.
e. B.Th.U.	6722.
Analysis of Coal as Fired.	
17. *a.* Fixed carbon	37·58.
b. Volatile matter	30·11.
c. Moisture	19·59.
d. Ash	12·72.
e. B.Th.U.	7928.
Water.	
18. Total water evaporated	204916.
19. Water evaporated per hour	20553.
20. Equivalent water evaporated from and at 212° Fahr.	22820.
21. Factor of evaporation	1·1103.
22. Water evaporated per lb. coal actual conditions	4·841.
23. Water evaporated per lb. coal from and at 212° Fahr.	5·375.
24. Quality of steam	95·54%.
Pressure.	
25. Steam pressure-gauge	136·3.
26. Draft at uptake in inches of water	·163.
27. Draft over fire	·032.
28. Barometer	28·67″.
29. Barometer	14·1 lb.
Temperature.	
30. Feed water—degs. Fahr.	109·4.
31. Flue gases	639·4.
32. Outside	79·5.
33. Boiler-room	97·9.
34. Furnace	1947·6.
Flue-Gas Analysis.	
35. 1st pass : CO_2	15·15.
O_2	0·26.
CO	0·0.
36. Breeching uptake : CO_2	14·55.
O_2	4·55.
CO	0·0.
Horse Power Developed.	
37. Rated h.p. of boiler	496.
38. H.p. developed from and at 212° Fahr.	661.
39. Percentage of rated h.p. developed	133·2.
Efficiency.	
40. Combined boiler and furnace efficiency.	77·59%.

R. N. Buell, writing upon the advisability of utilising in pulverised form the enormous brown coal deposits of Victoria, New South Wales, makes the following comparison between the thermal values obtainable for £1 sterling when firing this coal in lump form by hand or on mechanical stokers, and in pulverised form.

Victoria Brown Coal.	B.Th.U. actually utilised from 1 ton (2,240 lb.) of fuel.	B.Th.U. obtainable for £1 sterling. Brown coal 17*s*. + 13*s*. per ton cost of pulverising.
Hand-firing	6,720,000	7,905,880
Stoker-firing	7,840,000	9,223,520
In pulverised form	16,800,000	11,200,000

The provision made for cost of pulverising, 13*s*. per ton, appears to be an exceptionally heavy charge, no doubt due to the high rates of wages paid in Australia and to the relatively light nature of the fuel.

Cannel Coal.

As a fuel for use in pulverised form, cannel coal is exceptionally suitable either before or after treatment in distillation retorts. Cannel coal is usually a dry coal, rather high in ash. An analysis of Yorkshire cannel coal gives moisture 0·57 %; ash 21·15 %; volatile matter 25·91 %; fixed carbon 52·37 %; calorific value 12,190 B.Th.U. per lb.

Some notes based upon a report issued by the Lancashire and Cheshire Coal Research Association, prepared by F. S. Sinnatt and M. Barash, appeared in the *Engineer* of November 26, 1920, from which the following interesting extracts are taken :—

" The cannel coal is generally associated with seams of other coal and frequently forms the upper stratum. It has been investigated with a view to estimating its value for carbonisation, for the manufacture of cement and of pulverised fuel, or for use in gas producers. The analyses of a typical Hoo cannel and of the coal which accompanies it show that the main difference is one of ash content, the Hoo cannel having over 24 % ash, whereas the accompanying coal has 7·4 % only. The heat value of the Hoo cannel is 11,000 B.Th.U. and that of the accompanying coal 13,890 B.Th.U. The cannel contains roughly the same amount of nitrogen as the coal when the results have been caleulated to an ash-free basis. The sulphur content is rarely excessively high, being generally about 1·2 %, whilst there is a marked absence of pyrites.

" The Hoo cannel is very rich in volatile matter, and yields large quantities of volatile products during carbonisation. All samples of it tested have yielded a non-caking coke. Attempts to separate the ash content from the carbonaceous material by grinding and washing with a calcium chloride solution of 1·35 specific gravity proved unsuccessful, which leads to the conclusion that the ash is an inherent constituent of the cannel substance. The nature of Hoo cannel is such that it is very readily pulverised, much more readily than the accompanying coal."

Pitch.

Pitch as a metallurgical fuel has valuable characteristics and the softer grades are burned in a liquid state, but the hard pitch is quite readily burned as a pulverised fuel. For obtaining this in powdered form, special mills must be used, and only hard pitch having high melting points can be successfully treated

in this manner. An analysis of hard pitch shows that its calorific value can be as high as 15,928 B.Th.U. per lb.; moisture, 0·05 %; ash, 0·60 %; volatile matter, 66·85 %; fixed carbon, 32·55 %. It contains no sulphur, and is, to all intents and purposes, free from ash. It requires no drying, and can be successfully pulverised if its melting point in air is above 150° C. By means of centrifugal force, pitch can be reduced to shot of any size, and this process can be used for producing pitch powder suitable for firing in this manner.

Owing to its high calorific value and the almost entire absence of ash, hard pitch is an ideal fuel for special high heat work when completely burned, and this can best be effected when applied in shot or powdered form.

Waste Coal.

By pulverisation much fuel now considered useless can undoubtedly be rendered serviceable in many countries.

In connection with the utilisation of waste coal-dust Professor Louis (England) referred to this matter at a meeting of the Iron and Steel Institute :—

" He referred to what he might call natural coal-dust. Everybody knew that in coal-mining more or less dust was, unfortunately, always made. He could instance some South Wales mines in which the coal was rather brittle and dusty, where enormous quantities of coal-dust were made. He had been in some heap-steads in South Wales where he had walked ankle deep in coal-dust. Coal-dust was a deadly enemy in the pits, and all the big colliery explosions had been due to its presence. The present method of reducing the coal-dust danger was by stone-dusting—namely, mixing stone-dust with the coal-dust, and from time to time tramming out the mixture. It was perfectly possible by systems of dry blowing which had been used for years on a working scale—he did not mean experimentally, but year in and year out, on a big scale—to separate coal-dust from stone-dust and to get finely divided and very pure coal-dust exceedingly cheaply. Obviously, if it were possible to use such coal-dust in the way indicated, it opened up a very interesting vista to the coal-miner. It showed him the possibility of utilising economically and turning into money that which hitherto had been at its best a very great nuisance, and at its worst the deadliest source of danger against which the coal-miner had to fight."

In regard to these remarks, it may be clearly stated that freshly ground coal would, by reason of the bright unoxidised surfaces exposed, ignite more readily than " stale " coal-dust, or dust that had once been mixed with air and re-separated out. Stale or oxidised mine-dust could, however, be reconditioned quite readily if passed through a mill, which operation would produce both uniform fineness and fresh unoxidised surface. The suggestion made that coal-dust now left in a mine, to the detriment of health and life, should be brought to the surface is one that should be adopted, so that the fine dust in the workings would no longer present a risk of explosion and could well be burned under boilers at the mine or used in the vicinity of the colliery.

On this question of utilisation of waste fuel see also the remarks regarding anthracite, at p. 256.

In the final Report (1918) of the Coal Conservation Committee, appointed by

the British Government to consider and advise upon this matter, there is much useful information relating to the wastage of coal due to several causes at the mines.

One cause of wastage only will be referred to here, viz. that due to " casting back " into the workings a class of small coal ostensibly unsaleable. The quantity of such coal stated to be lost annually is 2,235,000 tons or 0·91 % of the total output of the coal mines in the year 1915. It is remarked that, whereas at some collieries 10 % of the output was cast back twenty years ago, at present such collieries were returning but 1 or 2 % of the annual output.

As to refuse fuel, the coal and shale or dirt tipped on to mine dumps, the report states that this amounts approximately to 8,046,935 tons, or 2·9 %, upon an annual output of 271,030,844 tons, of which record is available as to tip refuse proportion.

Much of the latter, and, without doubt, all in many cases, could be used in pulverised form, which, together with the 2,325,000 tons of small coal cast back into the workings, would mean the augmentation of general fuel supply by some ten million tons per annum.

Much of the refuse coal on mine dumps contains a high percentage of inert material. When this exceeds 30 or 40 %, it would pay to wash the coal. It might also conceivably pay to wash the coal containing a less quantity of ash in order to reduce the power expended upon haulage of useless inert material, and also to improve the output of burnable coal at the pulverising plants, with consequent reduced wear and tear expenditure on mill parts per ton of actual combustible.

That there is coal visible and in considerable quantity lying on mine dumps to-day is evidenced by a reference in the Press to the fact that during the coal strike in England in 1912 " over 3,000 tons of coal gathered free from pit banks in East Denbighshire have been consigned from Ruabon to several industrial centres within 30 miles of the collieries."

On this particular question of reclaiming much of the coal wasted at collieries, the author published the following notes in 1920 in consequence of certain statements which appeared in the *South African Mining and Engineering Journal.* In the December 1919 issue of the journal views were expressed as to the poor quality of South African coal for railway locomotive purposes. This alleged disqualification is more apparent than real when the prospect of burning South African coal in pulverised form is considered, for there is no reason why the daily production of " waste " coal (if not the accumulations of past working) cannot be used if pulverised, or why, thus treated, the so-called low-heat-value coals of South Africa, now ruled out for locomotive firing, should not be rendered serviceable.

In reviewing the mass of data collected on the subject, one is struck by the really consistent average heat values of the coal in South Africa, and especially by the normal small quantities of moisture contained in the coal in most instances.

In Brazil, a much more inferior grade of coal is being used on locomotives. The coal used in Brazil is compared with South African fuels in the following table :—

	Brazilian Coal undried.	Brazilian Coal; as used "dry" in pulverised form for locomotive fuel.	South African Coal; Undried.		
			Durban.	Kroonstad.	Dundee.
Moisture . . .	7·90%	1·73%	1·6 %	8·29%	0·84%
Volatile carbon .	28·04%	9·50%	27·10%	31·27%	25·3 %
Fixed carbon .	34·73%	61·50%	60·05%	45·32%	68·94%
Ash	28·93%	28·27%	11·25%	15·12%	5·76%
Sulphur . . .	3·16%	9·1 %	1·51%	1·43%	1·53%
B.Th.U. per lb. .	8,820	10,177	12,950	11,020	14,722
Evap. power . .	9·2	10·4	13·4	11·4	15·23

In connection with these analyses of coals, there are one or two points of outstanding interest. The second column of the Brazilian coal analysis represents the fuel in pulverised form after treatment in a rotary dryer. The fuel is of a friable nature, and the ash such that, when subjected to heat, it flows round the lumps of fuel on a hand-fired grate, rendering it impossible to burn the coal. Kroonstad coal contains about the highest degree of moisture recorded, 8·29 %, whereas most South African coal contains but 1 to 2 % of water, so that drying plant would certainly not be required.

Many references are made in the pages of the *South African Mining and Engineering Journal* to the friability of the fuel with consequent heavy loss in smalls and dust. This loss is eliminated when coal is pulverised.

Belt Pickings.

The wastage due to allowing lump coal, to which clay and shale adhere, to be classed with stone and slate is reprehensible. At many collieries good, sound, bright coal in large and small lumps is dumped to the extent of hundreds of tons per day. At some collieries this class of waste is used to a very limited extent, the coal and its attendant layer of shale being crushed to ½ in. size and hand fired under boilers. The ash content is in the neighbourhood of 35 %, and the calorific value generally about 7,500 B.Th.U. per lb.

It should be compulsory for every colliery owner to crush these selected belt pickings, wash the crushed product, and reclaim some 50 to 70 % of good usable coal from the bulk of material thus treated.

Cinder, Smut or Mother Coal (Fussain).

In some coalfields there is found a layer of rather soft, dead black or blackish-brown, dusty carbon deposit over the actual coal seam, or at times interspaced between the coal. This is termed cinder or mother coal, and has never been extensively used, although it often contains less than 10 % of inert material, is nearly always dry, containing 2½ % or so of moisture, and is of really high calorific value—upwards of 11,000 B.Th.U. per lb. This fuel should certainly be added to the long list of fuels usable in pulverised form, and should not be allowed to remain in the workings or dumped on the waste heaps. Because of its great friability, it is very easily pulverised, and, being dry, requires no expensive plant for its production as a pulverised fuel.

Smut of the following analysis has been made into commercial briquettes :—

Volatile matter, 33·16 %; fixed carbon, 37·58 %; sulphur, 4·15 %; moisture, 10·30 % (unusually high); ash, 14·81 %; calorific value, 12,410 B.Th.U. per lb.

Washery Sludge.

It is not so much what can be done as what is being done with waste fuel of this description about which readers studying the possibilities of pulverised coal firing wish to know.

Reference has been made to the successful boiler installation at the Seattle Power Station, where washery sludge is burned in pulverised form. The coal mined in this neighbourhood is sub-bituminous in nature, closely bordering upon lignite, and the washery waste had been accumulating for many years. Much of a 200,000-ton sludge dump has been, and the remainder is being, reclaimed through this method of firing. The material carries about 25 % moisture and (dry) averages 7300 B.Th.U.; volatile matter, 37%; fixed carbon, 38 %; ash, 23 %; sulphur, 1·0 %. The sludge is such that 50 % will pass the 10-mesh screen and is, therefore, totally unfit for either hand firing or stoker firing. Six thousand boiler horse power is developed at the Seattle Power Station, where this waste fuel is used.

Some approximate figures for washery sludge of general grade as recorded at some bituminous coal collieries in Derbyshire, England, are as follows :—

	Moisture.	Ash.	Combustible matter.
No. 1. Colliery Slurry, Wet	36·2%	22·6%	77·4%
,, ,, Air-dried	25·7%	20·8%	79·2%
No. 2. Colliery Slurry, Wet	30–36%	13–25%	75–87%
,, ,, Washer dirt. . . .	18%	43·3%	56·7%

These figures are representative of the masses of washery sludge thrown to waste, which contain high percentages of combustible matter rendering them entirely suitable for pulverised fuel, and collectively, they are of superior quality to the Seattle Slurry.

Oil Shale.

In some countries where deposits of high-grade coal are not found there are often supplies of the lower classes of fuel, lignite, brown coal, etc., but it must not be overlooked that other compositions of combustible rock or shale can be used in pulverised form. Oil shale, for instance, is best treated for distillation of its valuable liquid fuel content, but under certain conditions it might be advantageous to burn it in its natural state.

In Esthonia there are vast deposits of high-grade oil shale, which in lump form are used locally as fuel for domestic, industrial, and locomotive uses. Such fuel, if pulverised, would make an ideal fuel for many purposes.

The approximate analysis of Esthonian oil shale is as follows :—

	Moisture. %.	Sulphur. %.	Coke. %.	Volatile matter exclusive H_2O.	Ash. %.	Heating Power in Calories per kg.	Specific gravity.
Class 1 .	15–25	1·5 to 2·2	One-third of the organic components.	Two-thirds of the organic components.	25–35	2600–4000	1·2 to 1·4
,, 2 .	20–30				25–35	2800–3600	
,, 3 .	25–35				30–40 mainly $CaCO_3$.	2020–2800	

The chemical composition of the oil shale is :—

Locality of Shale.	C%.	H_2%.	N_2%.	O_2%.	S%.
Schamarin	70·5	7·2	0·2	22·0	—
Kogerman	71·58	7·4	0·48	19·04	1·5
Fokin	72·37–73·4	9·02	0·68	16·72	1·6–2·6
Sarembo	70·0	7·9	1·4	18·2	1·4–3·9

Indian and Eastern Coal.

As an example of the coal obtainable in the Eastern quarters of the globe, the characteristics of Burma coal can be taken as a fair average. All Burma coals are non-coking. Some are hard black and come away in lumps; others are crushed and can only be extracted as small coal; while many are friable and disintegrate on exposure to the air. The latter are grades eminently suitable for use in pulverised form. Some analyses of Burma coal are given hereunder :—

	Moisture.	Volatile matter.	Fixed Carbon.	Ash.
Burma Coal Co., Shwebo Lwindaw . .	18·42	32·1	47·62	1·86
Ketsobin 1	12·6	37·22	41·72	8·46
,, 2	9·52	29·84	21·56	39·08
Letkobin 1	11·94	37·68	36·22	14·16
,, 2	9·16	34·24	24·28	32·32
Chadouk	8·14	31·94	24·56	35·36
Kodaung	9·10	33·32	35·88	21·7
Letkobin Top	12·45	33·85	46·6	7·1
,, Bottom	10·02	36·25	38·8	14·9
Keteobin ⎫ Top	5·62	42·73	44·2	7·5
Outcrop ⎭ Bottom	8·55	40·6	36·65	14·23
Kodaung	6·22	33·03	36·85	13·9
Upper Chinwin (Av. of 11 samples) . .	10·14	34·59	49·95	5·3
Mergui Great A	15·2	30·08	30·86	23·86
Tenasserim River B	10·8	27·36	42·52	19·32
,, ,, C	11·34	36·4	43·27	8·99
Wet wun	17·78	34·48	39·47	8·27
	12·8	38·56	31·69	16·5

Classification of Coal in Various Countries.

By permission of Messrs. Babcock & Wilcox, the full and extremely useful table indicating the category in which coal should be placed, has been reproduced hereunder from *Steam*, the well-known book of reference upon fuel and boiler steaming results issued by that Company :—

These determinations are taken on an absolutely dry sample of large-size coal. A point to be carefully remembered is that the smaller grades of coal (unless they are well washed) have naturally a lower calorific value, owing to the higher percentage of foreign matter they contain, and that these lower grades of coal are those more generally used for mechanical firing.

HEATING POWER OF COALS OF UNITED KINGDOM, AUSTRALIA, CANADA, SOUTH AFRICA, AUSTRIA-HUNGARY, BELGIUM, FRANCE, GERMANY, RUSSIA, SPAIN, AND JAPAN.

Note.—The various coals have been classified according to the following definitions :—

Anthracite	3 to 7 % Volatile matter.
Semi-anthracite	7 to 12 % ,,
Semi-bituminous	12 to 25 % ,,
Bituminous	25 % & above ,,

UNITED KINGDOM.

Names of Coals.	B.Th.U.	Calor-ies.	A'prox % of vola-tile.	Nature.
ENGLAND.				
CUMBERLAND.				
Whitehaven . .	13,813	7,674	33·00	Bituminous
DURHAM.				
Horden . . .	14,133	7,851	34·68	
Lambton . . .	13,306	7,388	32·05	
,, . . .	13,340	7,407	31·14	Bituminous
Sherburn . . .	13,410	7,446	33·89	
S. Hetton, Hartley .	14,393	7,996	34·0	
Shotten . . .	13,590	7,550	23·09	
GLOUCESTERSHIRE.				
Crump Meadow . .	13,806	7,670	35·00	
Kingswood . . .	14,383	7,991	30·50	Bituminous
Trenchard . . .	14,112	7,840	25·80	
LANCASHIRE.				
Wigan Best . .	13,662	7,590	36·3	
,, Crombouke .	13,266	7,370	41·0	
,, Haigh Yard .	13,424	7,458	34·0	Bituminous
,, King . .	13,305	7,392	35·5	
,, Long Yard .	13,266	7,370	37·4	
LEICESTERSHIRE.				
Nailstone . . .	13,170	7,315	30·99	Bituminous
,, . . .	13,860	7,700	30·00	
NORTHUMBERLAND.				
Cowpen West Hartley .	13,725	7,625	31·73	
Hastings Hartley Main	13,876	7,709	34·17	
Ravensworth Hartley .	13,242	7,357	35·03	Bituminous
,, ,, .	13,242	7,357	33·04	
NOTTINGHAMSHIRE.				
Bestwood . . .	13,870	7,706	31·15	
Digby . . .	13,030	7,240	39·9	
Gedling . . .	14,037	7,798	30·25	Bituminous
Sherwood . . .	12,058	6,699	34·24	
,, . . .	12,348	6,860	32·3	
STAFFORDSHIRE.				
Ash Coal . . .	12,382	6,880	35·13	
Great Row . . .	12,568	6,982	40·8	
Talk-o'-the-Hill . .	14,402	8,001	31·3	Bituminous
Whitfield Cockshead .	14,304	7,947	30·9	
WARWICKSHIRE.				
Arley (mean) . .	12,952	7,195	37·71	
Griff	11,913	6,618	38·25	Bituminous
Newdigate . . .	11,400	6,333	37·6	
YORKSHIRE.				
Ackton Hall . .	14,800	8,222	35·0	
Best South Yorkshire .	14,616	8,120	32·85	
Black Bed . . .	14,295	7,942	32·36	
Dalton Main . .	14,358	7,977	35·28	
Dearne Valley . .	13,397	7,443	37·01	Bituminous
Denaby and Cadby Main	14,112	7,840	33·46	
Denaby Main . .	14,742	8,190	28·1	
Stanley Main . .	12,565	6,981	33·81	

Names of Coals.	B.Th.U.	Calor-ies.	A'prox % of vola-tile.	Nature.
SOUTH WALES. (Including Monmouthshire.)				
Blaina	15,535	8,630	5·09	
Carway	15,312	8,506	5·80	
Cawdor	15,312	8,506	6·30	
Cwragorse	15,372	8,540	6·30	
Garnant	15,523	8,624	6·00	Anthracite
Gwaun Cae Gurwen .	15,123	8,402	6·00	
Hook	15,494	8,608	4·70	
New Cross Hands .	15,341	8,522	3·80	
Ponthenry . . .	15,577	8,653	5·60	
Cory's Merthyr . .	14,500 to 15,000 depending upon the particular pit from which the coal is raised.	8,055 to 8,333	9 to 12	Semi-anthracite
Ferndale				
Hill's Plymouth Merthyr				
Lewis Merthyr . .				
Nixon's Navigation .				
Ocean Merthyr . .				
Penrikyber . . .				
Powell Duffryn . .				
Cory's Aberdare Merthyr	14,140	7,856	18·19	
Cory's Merthyr . .	13,552	7,529	12·36	
Glassbrook . . .	14,677	8,154	15·00	
Gt. Western Navigation	13,959	7,755	18·53	Semi-bituminous
Naval	14,380	7,989	16·37	
Phœnix Merthyr . .	14,924	8,291	16·80	
Pontardulais . .	13,561	7,533	12·32	
Tredegar . . .	14,652	8,140	14·52	
Elled Red Ash . .	13,532	7,518	29·97	
Clyne Valley . .	14,846	8,248	29·83	
John Blindell's Black Vein . . .	13,600	7,555	35·13	Bituminous
Newport Abercarn .	14,454	8,030	25·84	
Twnywain . . .	13,828	7,686	34·05	
SCOTLAND.				
Aitken Navigation .	13,768	7,649	24·47	Semi-bituminous
Alloa Jewel . .	14,016	7,787	36·93	
Alloa Splint . .	13,600	7,555	35·85	
Auchlochan . .	13,690	7,605	31·56	
Bowhill Navigation .	13,397	7,443	32·14	Bituminous
Dunnikier Navigation .	13,019	7,233	25·84	
Forth Crown Hartley .	12,094	6,719	32·84	
Glencraig Wilson Navigation . . .	13,870	7,706	25·32	
Herbertshire Navigation . . .	14,402	8,001	20·30	Semi-bituminous
Hirstrigg Semi-anthracite . . .	14,605	8,114	9·43	Semi-anthracite
Lochgelly Navigation	13,822	7,679	22·89	Semi-bituminous
Longrigg Navigation .	13,761	7,645	19·78	,,
McNaught Caprington .	12,422	6,901	36·65	Bituminous
Newbattle . . .	12,915	7,175	31·32	,,
Plean	14,064	7,813	21·83	Semi-bituminous
Polmaise Semi-anthracite . . .	14,880	8,266	12·72	Semi-anthracite

NEW SOUTH WALES.

Northern Coalfields.

Volatile hydrocarbons range from 29·32 to 41·60%
Fixed Carbons „ „ 48·85 to 57·90%
Heat Values „ „ 10,722 to 13,524 B.Th.U.
„ „ „ „ 5,956 to 7,511 Calories
and the average composition, calculated from about 77 analyses, is

Hygroscopic moisture	1·92%
Volatile hydrocarbon	35·09%
Fixed carbon	54·08%
Ash	8·91%
Total	100·00%

Southern Coalfields.

Volatile hydrocarbons range from 18·26 to 25·40%
Fixed Carbons „ „ 59·17 to 70·83%
Heat Values „ „ 10,915 to 12,944 B.Th.U.
„ „ „ „ 6,065 to 7,191 Calories
and the average composition, calculated from about 21 analyses, is

Hygroscopic moisture	·97%
Volatile hydrocarbon	23·10%
Fixed carbon	65·26%
Ash (including sulphur ·462)	10·67%
Total	100·00%

Western Coalfields.

Volatile hydrocarbons range from 26·11 to 34·75%
Fixed Carbons „ „ 46·65 to 56·01%
Heat Values „ „ 10,626 to 12,171 B.Th.U.
„ „ „ „ 5,900 to 6,762 Calories
and the average composition, calculated from about 13 analyses, is

Hygroscopic moisture	1·87%
Volatile hydrocarbon	31·49%
Fixed carbon	52·61%
Ash (including sulphur ·626)	14·03%
Total	100·00%

"*Note*—The above particulars are abstracted from the *Mineral Resources of New South Wales*, 1901 (Pittman).

WESTERN AUSTRALIA.

"Collie coal has a calorific value of about 70 % of that of the best Welsh coal.

Collie Coalfield.

Hygroscopic moisture	12·00%
Volatile hydrocarbon	29·34%
Fixed carbon	52·33%
Ash	6·33%
Total	100·00%

SOUTH AFRICA.

Names of Coals.	B.Th.U.	Calories.	A'prox % of volatile.	Nature.
NATAL.				
Central	12,867	7,148	15·87	Semi-bituminous
Durban Navigation	13,968	7,760	29·06	Bituminous
Elandslaagte :				
Bottom Seam	12,094	6,719	22·06	Semi-bituminous
Pit No. 2	12,867	7,148	22·54	
Farm Vaalbank	13,437	7,465	15·19	
Makatese Kop	13,495	7,497	23·43	
Natal Merthyr	12,702	7,056	19·39	
Natal Navigation	13,330	7,405	19·90	
Newcastle	13,852	7,695	28·96	Bituminous
No. 42 Colliery	12,026	6,681	25·65	
Utrecht	12,741	7,078	24·64	Semi-bituminous
West Lennoxton	12,770	7,094	28·50	Bituminous
TRANSVAAL.				
Heidelberg	10,864	6,036	21·81	Semi-bituminous
Middelburg Anglo-French (Transvaal) Navigation Coal	11·763	6,535	26·24	Bituminous
Middelburg Landau Coll.	12,517	6,954	28·31	
Middelburg Coronation Colliery	12,623	7,013	26·72	
Middelburg Douglas Colliery	11,937	6,632	22·88	Semi-bituminous
Middelburg Premier Coal	12,121	6,734	23·02	
Middelburg Rogerston Crown Colliery	11·560	6,422	22·74	
Middelburg Steam Coal	12·092	6,718	23·83	
Middelburg, Transvaal and Delagoa Bay Collieries	11,995	6,664	24·00	
Middelburg Uitbark Colliery	12,681	7,045	23·72	
Vereeniging	10,670	5 928	20·90	

CANADA.

Names of Coal.	B.Th.U.	Calories.	A'prox % of Volatile.	Nature.
ALERT BAY COALFIELD, VANCOUVER ISLAND, B.C.				
Pacific Coast Coal Co.	11,100	6,170	34·3	Bituminous
BELLY RIVER COALFIELD, ALTA.				
Alberta Railway and Irrigation Company	11,710	6,510	37·5	Bituminous
Canada West Coal Co.	11,040	6,130	36·0	
Lund-Breckenridge Coal Co.	9,810	5,450	30·1	
CASCADE COALFIELD, ALTA.				
Bankhead Collieries, Ltd.	13,320	7,400	11·8	Semi-anthracite
The H. W. McNeil Co.	13,210	7,340	17·2	Semi-bituminous

Name of Coal.	B.Th.U.	Calories.	A'prox % of Volatile.	Nature.
CROWSNEST COALFIELD, B.C.				
Coal Creek Colliery, No. 2 Mine	13,820	7,680	26·3	Bituminous
Hosmer Mines, Ltd., No. 8 Seam	13,990	7,770	28·0	
Michel Colliery, No. 8 Mine	13,480	7,490	24·1	Semi-bituminous
EDMONTON COALFIELD, ALTA.				
Parkdale Coal Co.	10,910	6,060	37·8	Bituminous
Standard Coal Co.	11,360	6,310	42·0	
Strathcona Coal Co.	10,730	5,960	41·0	

CANADA (*continued*)

Name of Coal.	B.Th.U.	Calories.	A'prox % of Volatile.	Nature.
FRANK BLAIRMORE COALFIELD, ALTA.				
Hillcrest Coal and Coke Co.	12,460	6,920	29·3	Bituminous
International Coal and Coke Co., Coleman Denison Colliery, No. 4 Seam . . .	12,530	6,960	23·9	Semi-bituminous
Leitch Collieries, Ltd. .	12,240	6,800	27·0	
West Canadian Collieries :				
Bellevue Colliery .	12,380	6,880	27·6	Bituminous
Lille Colliery .	12,470	6,930	25·0	
GRAND LAKE COALFIELD, N.B.				
G. H. King, King's Mine, Minto . .	12,890	7,160	32·2	Bituminous
INVERNESS COALFIELD, INVERNESS COUNTY, N.S.				
Inverness Coal and Railway Company : Inverness Colliery .	12,150	6,750	40·0	Bituminous
Richmond Railway Co., Port Hood Colliery .	11,770	6,540	37·1	
JOGGINS—CHIGNECTO COALFIELD CUMBERLAND CO., N.S.				
Canada Coal and Railway Co., Joggin's Colliery	11,590	6,440	36·6	
Maritime Coal, Railway and Power Co., Chignecto Colliery .	12,150	6,750	41·0	Bituminous
Minndie Coal Co., Minudie Colliery . .	11,830	6,570	35·7	
NANAIMO COMOX COALFIELD, VANCOUVER ISLAND, B.C.				
Wellington Colliery Co., Extension Mine .	13,160	7,310	40·1	
Western Fuel Co., Lower Seam, No. 7 Mine	12,980	7,210	28·0	Bituminous
Upper Seam No. 1 Mine	12,830	7,130	41·2	
NICOLA VALLEY COALFIELD, B.C.				
Nicola Valley Coal and Coke Co., Coutlee No. 2 Mine . .	12,170	6,760	39·0	Bituminous
PICTOU COALFIELD, PICTOU COUNTY, N.S.				
Acadia Coal Co. :				
Acadia Colliery .	13,860	7,700	26·0	
Vale Colliery . .	12,020	6,680	32·1	
Albion Colliery :				
Cage Pit Seam .	13,180	7,320	31·4	Bituminous
Allan Shaft Colliery .	13,230	7,350	33·3	
Intercolonial Coal Co. :				
Drummond Colliery .	12,960	7,200	24·7	
SOURIS COALFIELD, SASKATCHEWAN.				
Eureka Coal and Brick Co.	9,650	5,360	40·0	Bituminous
Western Dominion Collieries Co. . .	10,690	5,940	49·0	
SPRINGHILL COALFIELD, CUMBERLAND COUNTY, N.S.				
Cumberland Railway and Coal Colliery, No. 2 . . .	13,370	7,430	32·3	Bituminous
SYDNEY COALFIELD, CAPE BRETON COUNTY, N.S.				
Dominion Coal Co.'s, No. 1 Colliery . .	14,010	7,780	34·3	
North Atlantic Collieries . . .	12,620	7,010	34·7	Bituminous
Nova Scotia Steel and Iron Co.'s, No. 1 Colliery . . .	13,770	7,650	37·4	
WHITEHOUSE COALFIELD, YUKON TERRITORY.				
White Pass and Yukon Railway Co. :				
Lower Seam .	12,230	6,790	27·8	Bituminous
Middle ,, .	11,360	6,310	26·7	
Upper ,, .	12,060	6,700	25·0	

UNITED STATES OF AMERICA.

Coals. Locality of Beds.	B.Th.U.	Calories.	Nature.
Pennsylvania . .	14,221	7,892	Anthracite, having 88 per cent. of carbon.
,, . .	13,143	7,293	Cannel coal.
,, . .	13,155	7,301	Bituminious coking.
Kentucky . .	14,391	7,987	,, ,,
,, . . .	15,198	8,434	Cannel coal.
,, . . .	9,326	5,175	Lignite (good).
Illinois . . .	13,123	7,283	Bituminious coking.
Indiana . . .	14,146	7,851	,, ,,
,, . . .	13,097	7,268	Cannel coal.
Virginia . . .	13,100	7,270	Bituminous coking.
Arkansas . . .	13,075	7,364	Bituminous.

Full analyses of some thousands of car samples of American Coal are given in the Annual Report issued by the Bureau of Mines, Mines Department, Washington.

AUSTRIA-HUNGARY.

Coals. Locality of Beds.	B.Th.U.	Calories.	Nature.
LOWER AUSTRIA.			
Grünbach . . .	11,458	6,366	Semi-bituminous coal.
Thallern . . .	7,057	3,921	
UPPER AUSTRIA.			
Wolfsegg-Trannthal.	6,006	3,337	
STYRIA.			
Leoben . . .	9,666	5,370	Lignite or brown coal.
Fohnsdorf . .	9,187	5,104	
Göriach . . .	6,222	3,457	
Köflach . . .	6,867	3,815	
Wies . . .	7,997	4,443	
Trifail . . .	7,556	4,198	
BOHEMIA.			
Kladno . . .	10,675	5,931	
Buschtehrad . .	8,865	4,925	
Libuschin . .	9,900	5,500	Semi-bituminous coal.
Schlan . . .	7,979	4,433	
Rakonitz-Lubna .	7,257	4,032	
Pilsen . . .	9,318	5,177	
Schatzlar . .	9,552	5,307	
Aussig . . .	6,408	3,560	
Dux . . .	7,808	4,338	Lignite or brown coal.
Bilin . . .	8,182	4,546	
Brüx . . .	8,274	4,597	

AUSTRIA-HUNGARY (*continued*).

Coals. Locality of Beds.	B.Th.U.	Calories.	Nature.
Moravia.			
Rossitz	12,533	6,974	
M. Ostram	12,623	7,013	
Gaya	4,858	2,699	Lignite or brown coal.
Göding	5,056	2,809	
Silesia.			
P. Ostran	12,564	6,980	
Orlan-Lazy	12,389	6,883	
Poremba	11,057	6,143	Bituminous coal.
Karwin	13,021	7,234	
Taklowetz	11,932	6,632	
Hungary.			
Fünfkirchen	10,276	5,709	Cannel coal.
Anina	11,356	6,309	
Neufeld	5,200	2,889	
Brennberg	8,325	4,625	
Aika	6,913	3,841	
Salgo-Tarjan	7,966	4,426	Lignite or brown coal.
Dorog-Annathal	7,709	4,283	
Tokod	8,069	4,483	
Dalmatia.			
Siveric	8,087	4,493	Lignite or brown coal.
Istria.			
Arsa	10,182	5,657	Lignite or brown coal.
Transylvania.			
Petrozsény	11,286	6,270	
Egeres	8,692	4,829	Lignite or brown coal.
Bosnia.			
Zenica	7,911	4,359	Lignite or brown coal.

BELGIUM.

Coals, Locality of Beds.	B.Th.U.	Calories.	Nature.
Bassin de Mons.			
Haut-flenu	14,576	8,098	
Belle et Bonne, fosse No. 21	14,326	7,959	
Levant du flenu	14,508	8,060	
Couchant	14,446	8,037	
Midi	14,553	8,085	
Grand-Hornu	14,943	8,302	Semi-bitum. hard coal.
Nord du bois de Bossu	14,407	8,004	
Grand-Buisson	14,877	8,265	
Escouffiaux	15,217	8,454	
St. Hortense, bonne veine	15,107	8,393	
Bassin du Centre.			
Haine St. Pierre	14,702	8,168	
Bois du Luc	14,358	7,977	
La Louvière	15,127	8,404	Semi-bitum. coking coal.
Barcquegnies	15,363	8,535	
Mariemont	15,168	8,427	
Bascoup	14,911	8,284	
Sars-Longchamps	14,895	8,275	Bituminous hard coal.
Houssu	14,945	8,303	
Bassin de Charleroi.			
St. Martin, Fosse No. 3	14,954	8,308	
Trieukaisin	15,069	8,372	Semi-bitum. coking coal.
Poirier, Fosse St. Louie	14,421	8,012	
Bayemont, Fosse St. Charles	13,806	7,670	
Sacré-Madame	15,204	8,447	
Sars - les - Moulins Fosse No. 7	15,125	8,403	Semi-bitum. hard coal.
Carabinier-française No. 2	14,911	8,284	
Roton, veine Greffier	14,311	7,951	
Pont-du-Loup	14,947	8,304	

GERMANY.

Coals. Locality of Beds.	B.Th.U.	Calories.	Nature.
Ruhr.			
Dortmund	13,750	7,639	
Witten	13,750	7,639	Cannel coal.
Bochum	13,700	7,611	
Bommern	13,300	7,390	Short flame coal, semi-anthracite.
Essen	13,650	7,583	Cannel coal.
Lorraine.			
Saar-Coal	12,949	7,194	Cannel coal.
Saxony.			
Zwickau	11,964	6,647	
Hohndorf	11,343	6,302	Cannel coal.
Oelsnitz	10,674	5,930	
Lower Saxony, Anhalt & Brunswig.			
Unseburg	5,769	3,205	
Atzendorf	6,444	3,580	
Neudorf	6,093	3,385	
Görzig	3,852	2,140	Brown coal or lignite, low grade.
Halle a. S.	4,165	2,314	
Bitterfeld	3,830	2,128	
Naumburg	4,563	2,535	
Hanover.			
Osnabrück	10,789	5,994	Semi-anth., low grade.
Obernkirchen	12,718	7,066	Bituminous.
Silesia (Prussia).			
Carlssegen	10,422	5,790	
Myslowitz	10,758	5,977	
Waterloa	11,412	6,340	
Königshütte	12,247	6,804	Long-flaming, bituminous.
Paulusgrube	12,425	6,903	
Waldenburg	12,637	7,021	
Brandenburg	12,193	6,774	
Neurode	13,393	7,441	
Freienstein	9,651	5,362	Semi-bituminous.
Maxgrube	10,087	5,604	
Bavaria.			
Haushamer Coal	9,075	5,042	
Peissenberg	8,825	4,903	Low-grade coal.
Penzberg	8,449	4,694	

FRANCE.

Coals. Locality of Beds.	B.Th.U.	Calories.	Nature.
Bassin du Nord.			
Mines de Bruay	14,760	8,200	Very bituminous (Flénu)
,, Marles	14,760	8,200	
,, Bully-Grenay	14,670	8,150	Bitum. coal, long flamed
,, Liévin	14,760	8,200	
,, Lens	14,400	8,000	Bituminous coal.
,, Noeux	14,580	8,100	
,, Courrières	14,760	8,200	
Mines d'Anzin :			
,, Fosse Renard	14,400	8,000	
,, ,, St. Louis	14,400	8,000	
,, ,, Thiers	14,580	8,100	
,, ,, Bonne Part	14,400	8,000	Semi-bituminous.
,, ,, St. Waast	14,400	8,000	
,, ,, Vieux-Condé	14,400	8,000	
Mines de l'Escarpelle	14,040	7,800	Partially & semi-bitum. coal.
,, d'Aniche	14,400	8,000	Bitum. coal, non-coking.
Bassin de Saône-et Loire.			
Mines de Blanzy	12,735	7,075	Bitum. coal, long flamed.
,, ,, ,,	13,509	7,505	Anthr. coal, short flamed.
,, d'Epinac	12,888	7,160	Semi-bituminous coal, long flamed.

FRANCE (*continued*).

Coals. Locality of Beds.	B.Th.U.	Calories.	Nature.
Bassin de la Loire.			
Mines de la Loire .	13,850	7,689	Bitum. coal, long flamed.
„ Roche-la-Molière	13,694	7,608	Semi-bituminous coal.
„ Rive-de-Gier .	12,420	6,900	
„ Saint-Chamond	13,381	7,434	Bitum. coal, long flamed.
„ Montramber .	14,157	7,865	
Bassin de l'Aveyron			
Mines de Decazeville	13,928	7,738	Cannel coal.
„ Cransac .	13,928	7,738	
„ Campagnac .	13,928	7,738	

Coals. Locality of Beds.	B.Th.U.	Calories.	Nature.
Bassin du Gard.			
Mines de la Grand' Combe (Puits Trescol) .	13,500	7,500	Semi-bituminous.
„ Besèges (Puits la Valette) .	13,500	7,500	
„ Besèges (Puits Molières .	13,500	7,500	
Mines de Portes .	13,500	7,500	
„ Rochebelle .	13,500	7,500	Non-coking.
„ de Lalle .	13,500	7,500	Bituminous.
„ Nord d'Alais .	13,500	7,500	Semi-bituminous.
Bassin du Tarn.			
Mines de Carneaux .	13,500	7,500	Coking coal.
„ „ Albi .	13,500	7,500	
Bassin de Hérault.			
Graissessac . .	13,500	7,500	Semi-bituminous.

Russia

“ The most productive coal region of Russia is the Donetz Basin, in the province of Ekaterinoslaff, which covers an area of 16,000 square miles. Next in importance comes the Dombrova Basin in Poland—a continuation of the Great Silesian coal basin. Other coal regions are situated in the Urals, the Eskibastus district south of Omsk, the Kousnetski Basin (in the Government of Tomsk), and the Tkviboulski district in the Caucasus. Coal is abundant in Siberia, but the quality is poor.

“ Analyses of a few coals found in the South of Russia are as follows :—

LIDIEWSKY (RUTSHENKOVO).

(*Run of Mine*).

Volatile	34·1 %
Sulphur	1·55%
Ash	6·66%
Moisture	7·1 %
Heat Value	12,000 B.Th.U

CELESNEWSKI (OVRAGI).

(*Run of Mine*).

Volatile	(Approx.) 20%
Sulphur	1·84%
Moisture	4·29%
Heat Value	12,862 B.Th.U

SHERBINOWSKY KRIVOI TORETS.

(*Washed Peas*).

Sulphur	2·55%
Moisture	2·29%
Heat Value	13,527 B.Th.U.

RUTSHENKOWSKY (RUTSHENKOWO).

(*Run of Mine*).

Volatile	30·00%
Sulphur	0·77%
Ash	5·53%
Moisture	3·6 %
Heat Value	13·185 B.Th.U.

KORENIEFF AND SHYPILOFF. (MARIEWKA).

(*Run of Mine*).

Volatile	35·75%
Sulphur	2·54%
Ash	9·2 %
Moisture	3·62%
Heat Value	12,578 B.Th.U.

GOLUBOWSKY. GOLUBOWKA, ALMASNAIA.

(*Unsorted*).

Volatile	33·68%
Sulphur	2·63%
Ash	10·23%
Moisture	4·94%
Heat Value	11,806 B.Th.U.

Spain

“ The principal coalfields in Spain are situated in the provinces of Asturias, Lóen, Cordoba, Zaragoza, Barcelona, and Ciudad Real; of these the coal from the

Asturian field is considered the best. Below are a few analyses of coals from different districts.

ASTURIAS (Felechos).

Fixed Carbon	60·35%
Volatile Hydrocarbon	37·76%
Ash	1·91%
Heat Value	14,500 B.Th.U.

ASTURIAS (Felguera).

Fixed Carbon	63·95%
Volatile Hydrocarbon	33·54%
Ash	2·51%
Heat Value	14,250 B.Th.U.

ASTURIAS (Mieres).

Volatile Hydrocarbon	29 to 32%
Ash	8 to 9%
Sulphur	0·6 to 0·7%
Heat Value	13,500 to 14,400 B.Th.U.

LEON (Cinera).

Specific Gravity	1·20%
Moisture	2·00%
Ash	11·00%
Sulphur	1·5 %
Fixed Carbon	74%
Volatile Hydrocarbon	13%
Heat Value	13,500 B.Th.U.

ZARAGOSA (Utrillas).

Fixed Carbon	60·00%
Volatile Hydrocarbon	28·75%
Ash	11·25%
Heat Value	11,160 B.Th.U.

CORDOBA (Peñarroya) Fat coal.

Fixed Carbon	70·00%
Volatile Hydrocarbon	22·00%
Ash	10 to 12%
Heat Value	14,490 B.Th.U.

CORDOBA (Peñarroya) Semi-anthracite.

Fixed Carbon	82·00%
Volatile Hydrocarbon	10·00%
Ash	8 to 10%
Heat Value	14,580 B.Th.U.

CIUDAD-REAL (Puertoliano).

Fixed Carbon	59·90%
Volatile Hydrocarbon	34·65%
Ash	5·45%
Heat Value	10,800 B.Th.U.

Japan

"Japanese coals are generally bituminous in character and vary considerably in heating value; some of the best varieties, such as Takashima coal from the Kiushu district, being about equivalent in heating value to English Newcastle coal. Nearly all Japanese coals contain a large percentage of volatile matter."

The Drying of Wet Fuel (Peat).

That the drying of wet fuel in ordinary rotary kilns or dryers by means of evaporation may be out of proportion to the value of dry fuel recovered can be realised when the heat required for drying, say wet peat, is considered.

Assume, for instance, that 1000 kilograms of air-dried peat, containing 35 % of moisture, are to be "heat dried" down to 5 % moisture content, the fuel used for drying being similar air-dried peat containing 35 % of moisture burnt on a grate.

It is doubtful if more than 45 % overall thermal efficiency will be realised in such a dryer with this class of fuel, so this efficiency figure will be assumed.

It will also be assumed that the final temperature of the water vapour and gases leaving the dryer is 110° C.

The amount of water to be removed from the peat will be $1000 \times 35\ \% =$ 350 kilos.

Latent heat of vaporisation of water at 0° C. = 606·5 Cals. per kilo.

Mean specific heat over range under consideration may be taken as $0{\cdot}42 + 0{\cdot}000185\, t$; at 110° C. this equals 0·44035.

Then, $0{\cdot}44035 \times 110 = 48{\cdot}4385$ Cals.

$$48{\cdot}4385 + 606{\cdot}5 = 654{\cdot}9385 \text{ Cals. per kilo,}$$

say, 655 Cals. per kilo; and $655 \times 350 = 299{,}250$ Cals. per 1000 kilos of peat.

The dryer only works at 45 % efficiency, so that the heat actually required to drive off the moisture would be :—

$$229{,}250 \times 2{\cdot}22 = 508{,}935 \text{ Cals.}$$

The average calorific value of dry peat may be taken as 5000 Cals. per kilo, so that the peat in question containing 35 % of moisture will not have a higher calorific value than 3250 Cals. per kilo. Thus, the amount of peat used as fuel to evaporate the moisture will be : $\frac{508{,}935}{3250} = 156{\cdot}5$ kilos. These 156·5 kilos of peat used as fuel, however, also contain 156·5 × 35 % = say, 55 kilos of water, which have to be heated to the final exit temperature, 55 × 655 = 36,000 Cals., and for this purpose $\frac{36{,}000}{3250}$ = say, 11 additional kilos of peat must be used. We therefore find that the total quantity of peat used as fuel, 156·5 + 11·0 = 167·5 kilos.

The thermal equivalent of this peat used as fuel will be 167·5 × 3250 = say, 545,000 Calories required for the drying out of 350 kilos of water from 1000 kilos of peat, and

1000 kilos of peat containing 35 % moisture = 1000 × 3250 = 3,250,000 Cals.

1000 kilos of peat containing 5 % moisture = 1000 × 4750 = 4,750,000 Cals.

Thus, from the point of view of calorific value, 1000 kilos of dried peat are equal to $\frac{4{\cdot}75}{3{\cdot}25}$ = 1460 kilos of wet peat, and, weight for weight in terms of effective heat value, 1000 kilos of 5 % moisture peat would be equal to about 1627 kilos (1460 + 167) of 35 % moisture peat.

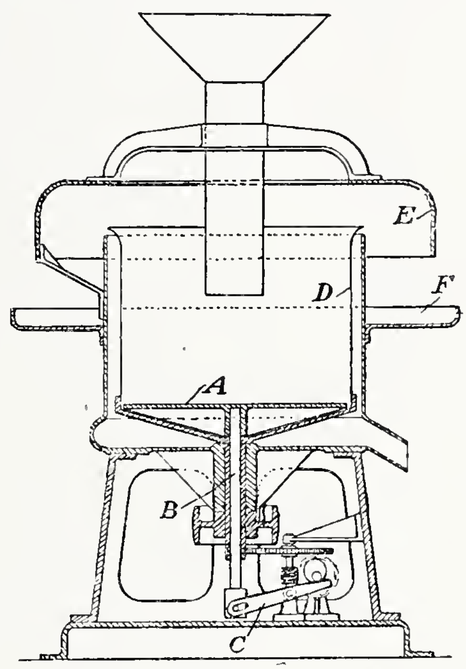


Fig. 3.—Continuous Feed and Discharge Centrifugal Hydro extractor.
The Engineer.

A false bottom A is mounted on a spindle B in such manner that it can rotate. At the lower end of the spindle B there is a lever C actuated by gearing. A is periodically raised and pushes the charge out of the basket D when it has been dried. The charge is caught by the cover E and drops on to the tray F.

To the actual cost of the peat, whatever this may be, must be added the cost of labour and capital charges on the dryer plant. If unlimited peat supplies are available and other fuel is relatively expensive, then it becomes purely a commercial calculation to find the market value of dried and preferably pulverised peat to meet industrial requirements.

So that the cost of extracting the heavy quantities of water from peat may be reduced to an economic figure, the author has endeavoured to find a method of moisture removal by means of a continuous feed and discharge centrifugal machine. An outline of the proposed hydro-extractor built on these lines is shown in Fig. 3.

The action of the machine is quite simple. Wet peat is delivered through the central spout on to the revolving bottom plate. The latter is actuated by cam motion so that the plate, while revolving at high speed, rises and falls to a slight extent and pushes up the material in course of drying. In this manner, wet fuel fed on to the revolving bottom plate immediately flies out to the draining cylinder, and in course of time becomes pushed to the top edge of the machine, where it is automatically discharged and collected in the dried state.

The power expended for extracting moisture in this manner is but a fraction of the calorific value of the fuel used to evaporate heavy percentages of water, quite apart from the capital charges for extensive heat-drying equipment.

CHAPTER V

NOTES ON COMBUSTION WITH SPECIAL REFERENCE TO PULVERISED COAL

Flame Temperature—Refractories and Linings—The Burning of Pulverised Fuel—Design of Combustion Chambers—Combustion and Nature of Ash in Fuel—Hand-Firing and Mechanical Stoker-Firing Conditions—Pulverised Fuel-Firing Conditions—The Chemistry of Combustion—Value of Analysing Products of Combustion—Calculation of Air necessary for Combustion of Fuel—Reduction in Excess of Air for Pulverised Fuel Firing—Calculation of Efficiency of Furnaces (Sources of Loss)—Water Tube Boiler Plant (Sources of Loss)—Metallurgical Furnaces (Sources of Loss)·

(*Combustion calculations, efficiencies and losses in this Chapter by H. S. Buckley*)

The art of preparing and burning pulverised fuel has advanced rapidly of recent years, and a very great mistake is made by those who refuse to entertain any discussion of the subject, because of the entirely unsuccessful, or only partially successful, results obtained ten or twenty years ago.

The improvements that have been made during the past few years in the design of plant and equipment, and in the study of the application of pulverised fuel for industrial uses, have established the success of this system. Failures may still be made, but it can be definitely stated that those failures will be entirely due to ill-considered schemes, or to faulty design of plant.

It must be frankly confessed that although pulverised fuel offers a great number of advantages in its combustion, it also presents some difficulties, which, if improperly dealt with, will render its successful use impossible. But there is no doubt whatever that in the majority of cases all recognised difficulties can be eliminated. Anyone considering the use of pulverised fuel need have no fear that the results guaranteed or specified by experienced engineers will not be attained.

Many questions must be thoroughly understood in connection with the burning of pulverised fuel, and some of these are reviewed hereunder.

Flame Temperature.

In the first place, the small amount of excess air used results in a relatively small volume of gas to be heated during combustion of the fuel and, consequently, the flame temperature of the fuel obtained in practice is greatly increased.

The theoretical maximum flame temperature of average coal when burnt in air is between 2000° C. and 2100° C. With 20 % to 25% of excess air, the average conditions for pulverised fuel firing, the maximum possible temperature will be between of 1800° C. and 1900° C.

Theoretical values are not realised in practice, but temperatures nearly approach-

ing theoretical temperatures are usually obtainable. Flame temperatures of high degree must, therefore, be considered if high thermal efficiency is to be secured.

One of the first difficulties to be overcome is to render a furnace lining capable of withstanding the high temperature of a pulverised coal flame.

Refractories and Linings.

Actual fusing points of industrial refractory materials have not yet been sharply defined, but the limits between which softening becomes marked are known with some accuracy.

Pure silica melts or softens very appreciably between 1600° C. and 1700° C. Commercial silica is obtainable in a more or less pure form, so that its melting point is at or about this temperature.

Pure alumina melts at about 2000° C. Commercial alumina is not usually obtainable in a pure state, and its melting point is about the same as for silica.

Bauxite, which contains a large percentage of alumina, melts at 1820° C., and this can be obtained without much difficulty.

Good quality bauxite will make a durable lining for many grades of ash, although when made up into bricks its melting point is seldom much above 1700° C. and it is somewhat costly.

Chromite consists largely of chromium oxide, and melts at about 2180° C., but this material is both expensive and difficult to obtain.

Silica, Alumina, Bauxite and Chromite are the four "high refractories" in general use.

Mention may here be made of two excellent but less known and more expensive refractory materials.

Pure Zirconia, or zirconium oxide, has a melting point approximating to 2200° C., and is obtainable in an almost pure state. It is, however, extremely dense, and as supplies are scarce and far afield, the present best known sources being in Brazil and India, freight charges and cost of collection and refining render this material expensive.

Carborundum has also a very high melting point, which varies according to the purity of the carborundum, but is usually well over 2000° C. It has a high thermal conductivity, which is an advantage for some applications. When used as a furnace lining it can be backed by a non-conducting material to reduce heat losses. Carborundum is probably one of the most durable of the known refractories obtainable commercially, but again the question of cost prohibits its use except as an inner lining or facing material.

The above are approximately the softening points of the well-known highly refractory substances, and it will be seen that the temperature of a pulverised coal flame is well up to the melting points of even the higher grades of the more readily obtainable refractories.

Difficulties arising from the fluxing action of iron oxide and alkalis, always found in the ash of coals, or the destructive action of lime or calcium oxide and alumina in the ash, which will readily combine with silica at high temperatures, must not be

overlooked, for all these factors have an important bearing upon the life of combustion chamber linings.

The fusing or fluxing of refractory linings can be overcome in practice only by arranging the combustion chamber in such a manner as to prevent the direct impingement of the flame on to the refractory lining. When designing pulverised coal fired furnaces, a direct " blow-pipe action " of a flame must be avoided, and, under the worst conditions, the flame should be projected parallel to, or should only strike a refractory brickwork surface tangentially.

The Burning of Pulverised Fuel.

Combustion areas must be such that a covering or " blanket " of cooler or more slowly moving gases is interposed between the actual flame and the furnace lining. In the earlier applications of pulverised coal firing these facts were very imperfectly understood, and lining troubles resulted.

When it is known that fuel will always be obtained from one particular source, the ash of that coal should be analysed, and a refractory most suitable for withstanding the destructive agents in the ash should be used.

Another difficulty experienced in the early days of pulverised fuel was that of maintaining continuous ignition and combustion. With pulverised bituminous coal, containing some 35 % of volatile hydrocarbons, the ignition of a correct mixture of the finely divided coal and air occurs almost immediately a lighted torch is applied, and no difficulty will be experienced in maintaining combustion, provided the flame so produced is not directed against a cold surface having a high thermal conductivity such as a boiler plate.

The explanation is not far to seek, as combustion is essentially a progressive operation. When a light is applied to a stream of coal and air (in correct proportions) the heat of the torch flame raises some of the particles of coal to ignition point, and local combustion occurs, which transmits further heat to adjacent particles of coal. These are in turn raised to ignition point, and so the action of ignition continues with ever-increasing rapidity. It follows that a fuel containing a high percentage of volatile matter having a lower ignition point will ignite and burn more readily, more rapidly, and more persistently than a fuel containing little or no volatile matter.

If, however, the particles of fuel as they burn come into contact with a higher heat-absorbing surface, for instance a boiler surface of greater conductivity than the surrounding particles of fuel, the ignited fuel will lose its heat to the boiler surface instead of raising the surrounding particles of fuel to ignition point. Combustion will cease, and the flame become extinguished. Volatile liquid fuels and rich gases may be burnt even in contact with cold boiler surfaces, because of the very low ignition points, and the persistency with which oil and gas will burn under the most adverse circumstances.

Even bituminous coals in pulverised form will not continue to burn in contact with a cold surface, so much the less is it to be expected that a pulverised low-volatile coal or anthracite fuel will do so. To introduce a pulverised fuel flame directly into the " cool " flue tube of, say, a Lancashire or similar type of boiler is

not a practice to be recommended, for any degree of combustion which may take place can be only in the very centre of the tube, and must be surrounded by a film of unburnt fuel and gas in contact with the cool surface of the tube.

If the whole of the heat due to combustion be absorbed by the products of combustion, and if these products could be surrounded by perfect heat-insulating surfaces, it follows that these products could then be transferred to a point of heat absorption some distance away from the zone of ignition without loss of efficiency. In other words, it would not be necessary to burn a fuel directly under or in contact with the surface to which we wish to transfer the heat in order to obtain efficient heat transference. In practice, however, owing to the impossibility of constructing entirely heat-proof surfaces, fuel has to be burned in contact with, or close to, the heat-receiving vessel, as, for instance, a boiler. Every effort should, therefore, be made to complete the combustion of a fuel as far as possible before the products are allowed to come into contact with heat-absorbing surfaces, otherwise it will be quite impossible to approach complete combustion.

Design of Combustion Chambers.

The exact arrangement of refractory linings will depend on the class of fuel used. With bituminous coal, furnace design is a relatively simple question, but for burning anthracite or pulverised coke it becomes essential, in certain circumstances, to arrange refractory arches or return walls so that the flame will beat back upon the incoming stream of fuel, and so maintain continuous ignition.

The velocity of gases within a combustion chamber is of great importance. It must primarily be sufficiently high to maintain the particles of pulverised fuel in suspension during the whole period of combustion. No particle of fuel should come in contact with any solid surface until combustion is complete. The smaller the combustion area available the finer the degree of pulverisation necessary, or the finer the degree of pulverisation the lower will be the permissible velocity of gases in the furnace.

If the velocity of the gases through the chamber be too high, the burning particles of fuel will be carried right through the combustion chamber, or into contact with the chamber end wall, before complete combustion is effected, and whilst the ash content in the fuel is at its maximum temperature and, therefore, perhaps in a plastic state. The ash particles, together with the remaining unburnt fuel, will then adhere to the furnace end wall or boiler tubes, and in this manner a coating of ash and slag will be built up.

The coarser the degree of pulverisation the longer the time that the particles take to burn, whilst the higher velocity required to keep them in suspension actually allows them a shorter time in which to burn. A good example of this is furnished in rotary cement kilns, where coarsely ground coal can be utilised successfully on account of the long chamber available, and the fact that the coal ash is mixed with the cement clinker without detriment.

The melting point of the ash from even the best coals is seldom in excess of 1450° C., and it is more often considerably lower, sometimes even as low as 1250–1300° C. Any ash in the actual flame or in its direct path will be in a semi-fluid or possibly

fluid state, in which condition it will readily adhere to other ash particles, or to the furnace wall or boiler tube with which it may come in contact. It is, therefore, desirable to remove ash from the zone of highest temperature as soon as the combustible matter has been burned. The ash should then fall or pass to a cooler zone below its melting point before coming into contact with other particles of ash or any part of the furnace lining. This can be readily accomplished in boiler firing, and in any circumstance in which combustion chambers of large area can be used, as the ash will then remain in a form in which it can be handled without difficulty. For metallurgical furnaces the question becomes more difficult, as with these it is naturally impossible to realise the simple conditions of boiler firing, when, by proper arrangement of the combustion chamber and the streams of fuel, and of the secondary air and the auxiliary ports for the admission of strata of fresh air to cool the falling ash, or again by the use of water screen tubes in the lower part of the chamber, a fair approximation to ideal conditions can be secured. With furnaces working at high temperatures it is often possible and sometimes advisable to run the ash off direct in a molten condition through suitable tap holes.

W. E. Willcox has demonstrated that, although pulverised coal has the characteristics of a rich fuel of somewhat higher kindling temperature than producer gas, natural gas or fuel oil, it also has a higher calorific value per cubic foot of mixture; thus a Pittsburg coal of 14,157 B.Th.U. per lb., of analysis 35·4% volatile matter, 58·5% fixed carbon, 6·1 % ash, a cubic foot of pure methane gas and correct proportion of air for complete combustion would develop but 62·3 B.Th.U., whereas a cubic foot of this coal in pulverised form would develop 107 B.Th.U. under similarly perfect conditions for complete combustion.

The same author refers to the rapidity of combustion of pulverised coal, showing that in Colorado, where a reverberatory furnace burns one ton of fuel per hour, the flame vanishes within 6 ft. of the burner orifice, and yet he points out that, by suitable adjustment of velocity of travel, a flame can be maintained for a distance of upwards of 100 ft. if required.

Combustion and Nature of Ash in Fuel.

Most users of fuel on a commercial scale are nowadays aware that combustion is a chemical reaction, involving the combination of carbon and hydrogen contained in the fuel itself with the oxygen of the atmosphere. The lack of efficiency in the better known and more widely used methods of burning fuel, and in the application of the heat so produced, is, however, not so widely appreciated.

Lack of knowledge concerning the proper combustion of fuel, and often lack of interest, have been in the past due largely to the fact that until some six or seven years ago the price of coal in many countries was so low that the expenditure on fuel represented but a small percentage of the total cost of a finished article. The heavy and permanent increases in the cost of coal which have now been established must in future compel engineers and fuel users to study the question of efficient utilisation of fuel much more carefully than heretofore.

It is obvious that the first step in this direction is to obtain efficient combustion, and, in order to show how this may be accomplished, it would be well to consider

briefly what occurs during the combustion of coal, this being the fuel of perhaps greatest importance in industry, and to point out the faults of the usual methods of burning it.

All forms of anthracite, bituminous coal, brown coal or lignite, together with intermediate varieties of solid fuel, consist chiefly of carbon. In addition, a percentage of hydrogen, varying from 2·5 % to 6 % by weight, is present, this being lowest in anthracites and highest in lignites and soft coals. These two elements, carbon and hydrogen, may be said to constitute the only important heat-producing elements of coal.

Small quantities of oxygen, nitrogen and sulphur exist in almost all coals, but, except for certain metallurgical operations, where the presence of sulphur is undesirable, they may be neglected, as they do not materially enter into practical combustion calculations.

The remaining constituent of coal, which is often of supreme importance, is the inert material or ash. The composition and quantity of the ash may vary over wide limits and have a very important bearing upon the result of combustion.

Ash consists chiefly of a mixture of alumina, silica and oxides of iron, together with small quantities of soda, potash, lime and oxides of other metals. Both alumina and silica, alone and in the pure state, are highly refractory substances. If combined in suitable proportions and fused together they form neutral compounds possessing a degree of refractoriness sufficient to resist the temperatures met with in the majority of industrial furnaces without further fusion.

On the other hand, should either the acid or basic constituent predominate, an unstable compound is formed which will attack the furnace lining if it be of opposite composition to the predominating constituent of the ash.

The amount of oxide of iron or other metal in the ash is also of very great importance, because almost all metallic oxides (with only a few exceptions) will lower the melting point of any refractory ceramic material with which they are mixed. Soda and potash have a similar very marked and deleterious effect.

It will, therefore, be readily understood that the composition of the ash present in a fuel is of equal or even greater importance than the actual amount of ash which the fuel may contain, so that a coal containing a fair amount of infusible ash may be of more commercial value than a coal of higher calorific value containing only a small amount of ash but of readily fusible nature.

It is equally evident that due consideration should be given to the composition of a furnace lining and also to the composition of the ash contained in the fuel to be burned. With these introductory notes on the composition of coal we may pass to its combustion.

Hand Firing and Mechanical Stoker Firing Conditions.

Consider first the oldest method of burning coal—that by intermittent hand firing. It is possible under these conditions to obtain anything from very bad to really good results; all depends on the skill of the fireman.

Assume for a moment that a hand-fired furnace, of any known type, requires a further supply of coal; the mass of the fuel already on the grate would almost

certainly be in an incandescent condition. This incandescent fuel is probably raked over by the fireman, who throws on a quantity of green coal. At once the temperature of the combustion chamber above the fire is reduced, for the screen of fresh coal blankets the radiation from the incandescent fuel bed. Quantities of volatile matter then begin to distil off the green coal; the greater portion of this volatile matter is gasified immediately by the heat from the lower bed of fuel. These gases are chiefly combinations of carbon and hydrogen which require several times their own volume of air for their complete combustion, and it is at this period that the fuel gives up almost all the hydrogen that it contains. To obtain complete combustion of these gases the air supply to the furnace must be temporarily and very largely increased, otherwise a considerable portion of this volatile and valuable part of the fuel will pass out unconsumed to the stack.

If the extra supply of air required at this stage be admitted above the fire (the best method from the chemical point of view), it tends further to reduce the temperature at the firing door and that of the combustion chamber, thus moving the zone of maximum temperature farther away from the actual fuel bed. This usually presents a very serious drawback in the case of certain internally fired boilers such as those of the Lancashire or Cornish type.

If, on the other hand, the excess air required for combustion of this volatile matter be admitted through the fuel bed, a large proportion of the oxygen contained in the air will be converted into carbon monoxide during its passage through the fuel, forming further combustible gas incapable of assisting in the combustion of the gases distilled from the green coal. In such circumstances the volume of unburnt gas passing to the flues and wasted will only be increased.

In practice, however, there is present such a large excess of air, which finds its way into the combustion chamber, both from above, from below, and through the fuel bed, that the combustible gases produced are usually burned, although very inefficiently, even at the period of maximum distillation of the volatile portion of the coal.

As the distillation of the hydrocarbons in the coal approaches completion, the fuel bed gradually becomes incandescent throughout, at which stage the solid carbon of the fuel is consumed at a much slower rate, and consequently a much lower air or oxygen demand is presented than just after the addition of fresh fuel. Unless, therefore, the fireman is skilled and careful in the adjustment of his air supply, much more air than is required for combustion enters the furnace. The inrush of excess air is, moreover, intensified by the fire burning into holes at various points on the grate, allowing air to pass freely and directly into the combustion chamber without effecting chemical combination with any portion of the fuel.

It is obvious that the whole of this excess of air supply, which, under bad conditions, may amount to three or four times that actually required by the fuel, has to be raised to the temperature of the combustion chamber.

If the whole of the heat absorbed in this manner by the excess air present could be imparted to the boiler or material to be heated, it would not impair the overall efficiency of the system. In practice, better economy is obtained by storing a given quantity of heat in a small quantity of furnace gases at high temperature than in a

large volume of relatively low temperature gases due to addition of excess of air. It clearly follows that excess of air always means needless waste of fuel in the form of hot gases leaving the furnace chimney.

For hand-fired furnaces it is, therefore, necessary that skill and judgment be exercised to regulate the air supply in accordance with the requirements of the fire, and that constant care and attention be given to prevent the formation of holes in the fuel bed, and to see that fresh fuel is added only in small quantities. If all these requirements be attended to, the opening and closing of the fire-door will still allow uncontrollable quantities of cold excess air to enter the furnace; furthermore, unless very good fuel be available, the cleaning of the grate bars must be carried out frequently, during which operation the efficiency of the furnace drops practically to zero.

All these factors combined fix the average overall thermal efficiency of a hand-fired steam boiler at about 55 % when good coal is used, and hand-fired furnaces for metallurgical or other purposes would show an efficiency of about this figure. For short periods the overall efficiency of a hand-fired boiler may, and sometimes does, reach 75 % with a particularly skilful fireman, but efficiencies of 40 % and even less are often recorded on test. An average figure of 55 % is, therefore, good normal practice.

In order to eliminate many of these bad features of hand firing, and to cope with the increasing size of furnaces designed for solid fuel, the many commercial types of mechanical stokers were invented. These have for their main objects :—

(*a*) Elimination of the variability of the human element as far as possible.

(*b*) Maintenance of regular firing rates within predetermined limits and regular furnace conditions, both chemically and physically, over long periods.

(*c*) Reduction in the cost of boiler operation.

The degree of success obtained with mechanical stokers, when considered purely from the technical point of view, varies very greatly, and for some of the early types the cost of repairs and maintenance was frequently in excess of the value of the fuel saved.

Modern mechanical stokers, however, give very good and reliable results over long periods of operation at or about their rated capacities, but the rate of fuel burned per hour cannot be much increased, especially when high ash fuel is to be used.

The class of fuel that can be burned on a mechanical stoker is, to a large extent, limited by the design and adjustment of the stoker.

Pulverised Fuel Firing Conditions.

Now consider the burning of solid fuel in lump form on any type of grate. It is well known that if any two substances are to be chemically united it is desirable to subdivide those substances as much as possible before proceeding to combine them. It is equally well known that a given weight of fuel when divided into small pieces will burn more rapidly and completely than when it is in one piece.

For example, as we have already pointed out, a cubic inch of coal when in one piece only exposes six square inches of surface to the action of heat and oxygen, and the interior portion of the cube is not subjected to oxidising action until the

exterior surface has been consumed, although volatile hydrocarbons will be driven off from the mass as soon as the interior temperature and pressure are sufficient to effect this. But the standard of fineness to which coal is pulverised, prior to burning in a furnace in this form, is such that 85 % of the pulverised fuel will pass through a 200-mesh sieve; or, in other words, a cubic inch of coal is divided into at least 20 to 30 million separate particles, increasing the exposed surface of the same weight of coal to from 300 to 400 times that of the solid cubic inch. In this state the intimate and almost complete mixture of fuel and oxygen can be effected in the correct proportions prior to ignition of the mixture, and so combustion is almost instantaneous and complete. The fuel, intimately mixed with air, burns as a gas, and, moreover, there is theoretically no necessity for any excess of air.

The Chemistry of Combustion.

The ease with which it is possible to obtain a correct mixture of solid fuel and air, and to effect complete combustion with little or no excess of air, is the chief reason for maintaining that the burning of solid fuel in pulverised form is superior to any other known method of utilising the heat-producing elements of coal, or other solid fuel in its natural state. There are other advantages, which will be mentioned later, but this is the fundamental advantage, and answers the question so often asked, why we should go to the trouble and expense of reducing fuel to a powder when it can be so readily burned on grates in the lump.

From the point of view of the utilisation of solid combustible matter to the best effect, the second great advantage of pulverising fuel lies in the possibility of using many fuels in this form which, otherwise, are valueless because of their inherent physical and chemical defects. Many of the so-called " useless " fuels are useless only because of the nature or the amount of the ash which they contain. This question is referred to in greater detail in Chapter IV. Stated briefly, it may be said that, from the point of view of combustion, pulverised fuel is the most successful method at present known of putting solid fuel on an equal basis with the high-combustion efficiencies of oil and gaseous fuels.

It may be well to give some figures showing exactly what the various losses so far pointed out may amount to in actual practice; but to understand how the value of each loss is arrived at it is necessary to have some knowledge of what takes place when fuel burns.

Combustion is essentially a chemical process or reaction involving the union of two or more substances or elements, such union resulting in the generation of heat. Strictly speaking, the term combustion includes the union of a considerable number of chemical elements, and oxygen need not in every case be one of these elements. For our present consideration, however, we can confine our attention to carbon, hydrogen and oxygen, for these are the elements chiefly concerned in the majority of commercial combustion problems.

In all industrial applications the oxygen required by the fuel is obtained from the air. Air is a mechanical mixture of some 20·19 % of oxygen and 79·09 % of nitrogen, or by volume roughly four parts of nitrogen to one of oxygen. Nitrogen is a comparatively heavy gas, and, as far as the problems reviewed in the following

calculations are concerned, it is an inert gas playing no part chemically in the combustion of fuel.

Oxygen combines readily with the majority of other chemical elements. It is capable, moreover, under favourable conditions, of withdrawing many of these elements from existing combinations, and itself entering into combination with the elements so withdrawn. This process is invariably accompanied by a rise of temperature, which facilitates the process by weakening the bonds which unite the molecules. This additional application of heat further raises the temperature and accelerates the oxidation.

Whether the process takes place slowly at comparatively low temperatures, as when the carbon in our blood, as it passes through the capillaries of the lungs, combines with the oxygen in the incoming breath and passes away with the outgoing breath; or more rapidly, as in the burning of any ordinary fuel; or more rapidly still, as when starting up a furnace by applying a lighted torch to a mixture of coal gas and air, or of coal dust and air; the only varying factor is the rate of the reaction, and we may reasonably apply the term combustion in all cases, and speak of the two extremes respectively as slow combustion and explosive combustion (or briefly explosion). The latter is so called by virtue of the mechanical effects of the sudden change of volume brought about by the correspondingly sudden generation of heat.

Thus, if we take a sample of coal and expose it to the atmosphere for a sufficiently long period to enable it to lose 1 lb. of carbon by what may be termed exceptionally slow oxidation, the total generation of heat will be the same as when 1 lb. of the coal is burned on a fire, or when 1 lb. of it is finely ground, intimately mixed with oxygen, and exploded.

Before passing on to practical combustion calculations, it may be well here to recapitulate briefly the elementary chemical combinations and reactions, and to explain present-day advanced modifications of old-established principles, which make it possible, by weighing both the coal supplied to a furnace during a trial run, and the residue of ash (in combustible solid matter) left on the grate, also measuring the volumes of the gaseous products of combustion, to obtain a quantitative determination by weight of all the products of combustion.

It was in 1802 that John Dalton first obtained definite evidence that the structure of matter is granular. Soon afterwards Gay-Lussac found that gases combine in simple volumetric proportions. In 1811 Avogadro pointed out the distinction between the molecules and the atoms which compose them, and proposed, as a working hypothesis, the natural assumption that equal volumes of dissimilar gases contain, under similar conditions of pressure and temperature, equal numbers of molecules. It was at that time possible to make comparisons only, and hydrogen, as the lightest gas, was taken as a standard, its atomic weight being called unity and its molecular weight 2, for acceptance of "Avogadro's Law," as it is called, involves the conclusion that simple gases, such as hydrogen and oxygen, consist of molecules containing at least two similar atoms in combination with each other. This law has since been shown, by thermodynamic reasoning, to be absolutely true for the ideal, or so-called perfect gas of the mathematical physicist. It has also been shown experimentally to hold good, to an extremely close approximation, in

the case of gases, such as hydrogen, oxygen, nitrogen, which, under normal conditions, are very far from the pressure and temperature of liquefaction, and to a fairly close approximation, sufficient for all practical purposes, to such gases as carbon monoxide and dioxide. To such approximation we may therefore define a gram-molecule, known as a mol., as the volume of a quantity of gas which has a mass equal to its molecular weight in grams. It is constant for all gases, and at a pressure of one atmosphere and temperature 0° C. is equal to 22·412 litres, or 22,412 cubic centimetres, which is the volume, under these conditions, of a weight of 2 grams of hydrogen, or, to be exact, of a mass of 2 grams of hydrogen, since a mass of 2 grams is a definite quantity, while the weight varies very slightly at different places on the earth's surface.

The advances since Avogadro's time in our knowledge of the nature of atoms and molecules, and in the discovery of many new elements, and of vastly improved methods of determining atomic weights (atomic masses), have fully justified the expression of the atomic weights in terms of that of hydrogen. They have also shown that atomic weights, so expressed, should be whole numbers, but also that the experimentally determined values differed by much more than could be accounted for by experimental error. The discovery that many of the supposed elements consist of mixtures of two or more elements, identical in chemical properties, but differing by 1, 2, or more units in these atomic weights (isotypes they are called), accounted for many of these cases. But there remained very appreciable deviations; the numbers obtained for carbon and oxygen, for instance, exceeded 12 and 16 respectively, though there were many indications that these old-established figures should be their values. The indication of the series of elements, as a whole, was that, retaining the expression of their atomic weights in terms of that of hydrogen, the latter should be taken as 1·008, instead of unity, which makes the weight (or mass) of the mol. 2·016 grams instead of 2 grams. In all other elements the molecular weights, being double the atomic weights, and expressed in terms of the molecular weight of hydrogen as the unit, will be unchanged by changing the unit from 1 to 1·008, so that *e. g.* a mol. of carbon will have a mass of 24 grams and a mol. of oxygen will have a mass of 32 grams. It will be seen, however, that the old approximation of 1·0 for the atomic weight of hydrogen and 2·0 grams as the mass of a mol. of hydrogen are sufficiently accurate under practical conditions, and have been adopted accordingly in making the following calculations.

With the exception of the small number of inert gases—helium and argon are examples—which are incapable, under any conditions that we have been able to subject them to, of entering into combination with other elements (their atoms do not even form molecules by combining with each other, so that these gases are monatomic), all the elements are capable of combining with others to form compounds. Each of these has a eertain number of links (of electric nature) with which it can link itself to another atom or other atoms of similar or different kind. The number of links possessed by the atom of any element is called the valency of that element. The following table gives the name, the symbol representing an atom, the valency and the atomic weight of each of five elements with which we have to deal in considering the combustion of coal.

Name.	Symbol.	Valency.	Atomic Weight.
Hydrogen	H	1	1·0 (1·008 theoretical)
Oxygen	O	2	16
Carbon	C	4	12
Nitrogen	N	5	14
Sulphur	S	6	32

Any number of atoms greater than unity of an element existing in a molecule is indicated by writing the number as a subscript to the element, so that CO_2 represents a molecule of carbon dioxide consisting of 1 atom of carbon and 2 atoms of oxygen chemically combined.

In this book extreme accuracy of chemical calculations is unnecessary; the closely approximate results given later as examples of boiler or furnace efficiencies serve the purpose intended.

Considering first the combustion of pure carbon, we can represent this combination as follows, taking the smallest quantities which represent a complete reaction :—

$$C_2 + 2O_2 = 2CO_2.$$

That is to say, 1 molecule of carbon and 2 molecules of oxygen are broken up and form 2 molecules of another compound, carbon dioxide (CO_2).

Taking sufficient molecules of C to give 2 gr. $\times$ 12 and a corresponding quantity of O according to the above equation, it will assume the form 24 gr. C + 64 gr. O = 88 gr. CO_2, from which the weight of any two of the three substances C, O, CO_2 can be found when the weight of one is given. If the volumes of the gases are to be measured instead of their weights, the equation may be written 24 gr. C + 2 mols. O = 2 mols. CO_2, 2 mols. O weighing 64 gr., and 2 mols. CO_2 weighing 88 gr. This equation shows that, to the approximation to which Avogadro's law holds good for the gases O and CO_2, the volumes on both sides of the equation are equal, there being the same number of molecules in 2 mols. CO_2 as in 2 mols. O, so that the carbon contributes nothing to the volume, but simply increases the weight (mass) of each molecule in the ratio of 44 to 32, *i. e.* of the molecular weight of CO_2 to that of O.

This combination is always accompanied by the evolution of a definite and unvarying amount of heat from a definite weight of carbon. The carbon, having satisfied its demand for oxygen, will not enter into further combination with any additional oxygen present, nor, under the conditions of normal combustion, will it enter into combination with any nitrogen present.

Therefore, if a given quantity of carbon be burnt in an unlimited supply of air, it will automatically extract from that air supply just the amount of oxygen it requires, leaving the nitrogen previously mixed with such oxygen unchanged, together with the remaining surplus air. The free air, together with the surplus nitrogen and the carbon dioxide, all being gases, will then mix, and together they will form the "products of combustion" or waste gases. If, however, the air supply is restricted to the exact amount necessary to form the higher oxide (CO_2), the resulting

products of combustion will consist only of carbon dioxide (CO_2) and nitrogen (N_2), with no free oxygen. It will thus be seen that an analysis of the products of combustion will clearly indicate whether too little, too much, or just sufficient air has been supplied. In the case of insufficient air supply carbon will combine with oxygen to form the lower oxide, carbon monoxide (CO) as follows :—

$$C_2 + O_2 = 2CO$$

in which case 1 molecule of carbon and 1 molecule of oxygen are broken up and form 2 molecules of carbon monoxide.

Carbon monoxide is a combustible gas, and if supplied with a further amount of oxygen it will burn to form carbon dioxide, thus :—

$$2CO + O_2 = 2CO_2.$$

An intermediate oxide of carbon between CO and CO_2 has not been discovered, so that if a given quantity of carbon is supplied with more than sufficient air to form CO, but insufficient to form CO_2, we may have a mixture of carbon monoxide (CO), oxygen (O_2) and nitrogen in the waste gases.

The other element of importanee usually found in fuels is hydrogen (H_2), although this can be taken to be always much smaller in quantity than the carbon. As the result of the combination of hydrogen and oxygen, which readily takes place, water (H_2O) is formed, thus :—

$$O_2 + 2H_2 = 2H_2O$$

and, as in the other combinations mentioned, heat is evolved during the process.

If hydrogen alone be burnt in an excess of air, the products of combustion will consist of water vapour, oxygen and nitrogen, but if the supply of air be insufficient for the whole quantity of hydrogen present, the available oxygen in this air supply will be taken up by the hydrogen, leaving a mixture of water vapour, hydrogen and nitrogen. A higher oxide of hydrogen is known, but it would not be produced during ordinary combustion in air. Due to the combustion of carbon and hydrogen in air, we find in the products of combustion a mixture of water vapour, carbon dioxide and nitrogen, provided that only the correct quantity of air has been supplied. If too little air has been supplied, then carbon monoxide will be present in the products of combustion, and if too much air has been supplied, then oxygen will appear in the waste gases.

Value of Analysing Products of Combustion.

It will thus be seen that an analysis of the products of combustion affords a very reliable indication as to the efficiency obtained. This fact has resulted in the development and use of a large number of instruments of various designs, hand-analysis apparatus, and automatic recording meters, with the object of ascertaining and recording the degree of efficiency developed at any one moment, or over a continuous period of firing.

Although analyses taken intermittently at comparatively long intervals will

give useful records, it is obvious that an instrument producing a continuous record of the analysis of the waste gases is much more valuable. A portable hand apparatus used for making intermittent analyses of the carbon dioxide, oxygen, carbon monoxide and hydrocarbons in flue gases is shown in Fig. 4.

In making an automatic apparatus of this class, it would be quite impossible to produce a *practical* instrument capable of dealing with this complete group of gases, not only on account of the complication and delicacy of the parts, but also on account of the slowness of absorption in the case of the oxygen and carbon monoxide, and because there are other complications regarding the determination of the hydrocarbons.

For all practical purposes the amount of carbon dioxide (CO_2) in the waste gases renders a sufficiently accurate indication of combustion conditions when the average analysis of the fuel used is known, and the determination of CO_2 is rapidly and easily made by the use of a plain solution of caustic potash.

In the author's opinion one of the most useful, accurate and reliable Automatic CO_2 Recorders yet invented is that shown in Fig. 5. This has been brought almost to perfection by a leading American combustion engineer, J. W. Hays, and it has proved entirely reliable and accurate under everyday working conditions. A recording draught gauge is incorporated in the same instrument, so that the furnace operator can readily adjust the draught conditions in order to obtain a constant and high average CO_2 reading.

It has been shown that the maximum percentage of CO_2 (due to complete combustion of pure carbon) in the waste gases, when fuel is burned under ideal conditions in air, is 20·91 % by volume. Absolutely pure carbon without any other combustible material is, however, seldom, if ever, met with in commercial practice. Hydrogen in greater or less proportions is always present in combination with the carbon. Small quantities of sulphur and oxygen are also present as a rule. Hydrogen and sulphur, when subjected to combustion, form respectively water vapour and sulphur dioxide as waste products.

Under best firing conditions there will never be more than 20 % of CO_2 in the products of combustion of ordinary solid fuel, and in practice 16 % or 17 % CO_2 indicates exceptionally efficient combustion.

Calculation of Air necessary for Combustion of Fuel.

No system has yet been devised by means of which fuel can be burnt at 100 % efficiency, and in order to determine the actual degree of efficiency reached in practice, it is necessary to know the theoretical maximum CO_2 that can be obtained with the fuel used.

Take, as an example, a coal of the following composition : total carbon 76·38 %; hydrogen 4·71 %; oxygen 5·70 %; nitrogen 1·59 %; sulphur 1·04 %; ash 10·58 %. We wish to ascertain the amount of air required for complete combustion of the fuel and also the theoretical composition of the waste gases. The burning of this coal will yield products of combustion containing carbon dioxide (CO_2) from the carbon, water vapour (H_2O) from the hydrogen, and sulphur dioxide (SO_2) from the sulphur. In addition, there will be the amount of nitrogen accompanying the oxygen taken

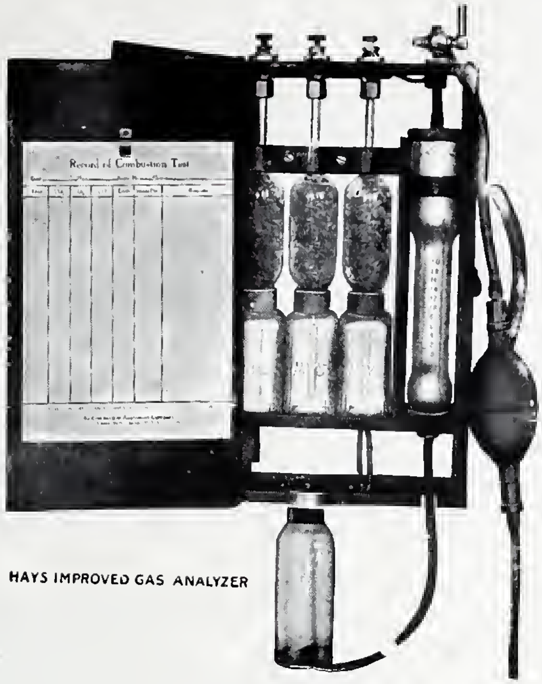


FIG. 4.—HAYS PORTABLE GAS ANALYSIS APPARATUS.

The Jos. W. Hays Corporation.]

[*Duguid Instrument Co., Manchester*

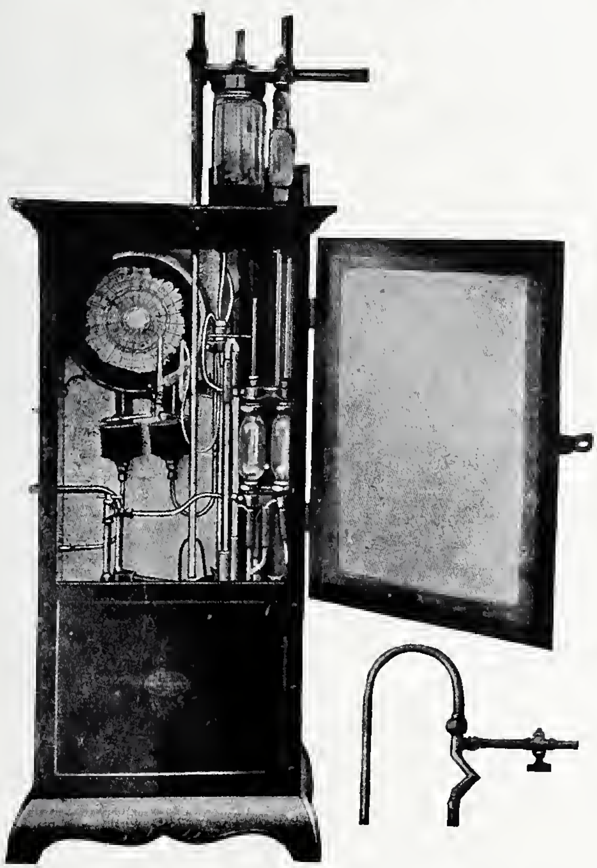


FIG. 5.—HAYS CO_2 RECORDER INSTRUMENT.

The Jos. W. Hays Corporation.]

[*Duguid Instrument Co., Man hester.*

[*To face p.* 76.

from the air and the small quantity of nitrogen contained in the coal itself. The various chemical reactions may be represented as follows :—

(A) (carbon) $C_2 + 2O_2 = 2CO_2$

or $24\text{ g. C} + 64\text{ g. O} = 88\text{ g. } CO_2$

or $24\text{ g. C} + 2\text{ mols. O} = 2\text{ mols. } CO_2$.

(B) (hydrogen) $2H_2 + O_2 = 2H_2O$

or $4{\cdot}032\text{ g. H} + 32\text{ g. O} = 36{\cdot}032\text{ g. } H_2O$

or $2\text{ mols. H} + 1\text{ mol. O} = 2\text{ mols. } H_2O$.

(C) (sulphur) $S_2 + 2O_2 = 2SO_2$

or $64\text{ g. S} + 64\text{ g. O} = 128\text{ g. } SO_2$

or $64\text{ g. S} + 2\text{ mols. O} = 2\text{ mols. } SO_2$.

We will consider the products of combustion from 100 grams of the coal of the given analysis, so that the percentage figures will represent the actual weight in grams of the amount of the particular element under consideration.

To find the volume of the products of combustion the process is as follows :—

12 grams of carbon burn to form 1 mol. of CO_2, and 76·38 grams will give $\frac{76{\cdot}38}{12} =$ 6·365 mols. CO_2.

Similarly, 2 grams of hydrogen produce 1 mol. of H_2O, and 4·71 grams will give $\frac{4{\cdot}71}{2} = 2{\cdot}355$ mols. H_2O.

Also, 32 grams of sulphur produce 1 mol. of SO_2, and 1·04 grams will give $\frac{1{\cdot}04}{32} = 0{\cdot}0325$ mol. SO_2.

The oxygen required for combustion is :—

$$\left.\begin{array}{ll} 6{\cdot}365 & \text{mols. for the carbon} \\ 1{\cdot}1775 & \text{,, ,, ,, hydrogen} \\ 0{\cdot}0325 & \text{mol. ,, ,, sulphur} \end{array}\right\}\text{Total} = 7{\cdot}575 \text{ mols. of } O_2.$$

There are, however, 5·7 grams of oxygen in the fuel, the corresponding amount of which is $\frac{5{\cdot}7}{32} = 0{\cdot}178$ mol.

Therefore, O_2 required from the air is $7{\cdot}575 - 0{\cdot}178 = 7{\cdot}397$ mols.

This oxygen would carry with it $7{\cdot}397 \times \frac{79{\cdot}09}{20{\cdot}91} =$

$$7{\cdot}397 \times 3{\cdot}78 = 27{\cdot}9 \text{ mols. of nitrogen.}$$

The coal also contains 1·59 grams of nitrogen =

$$\frac{1{\cdot}59}{28} = 0{\cdot}0566 \text{ mol.}$$

Total nitrogen is then $27{\cdot}9 + 0{\cdot}0566 = 27{\cdot}9566$ mols.

The products of combustion would, therefore, contain :—

		Mols.	Percentage.
Carbon dioxide (CO_2)	=	6·365	17·311 %
Water vapour (H_2O) (uncondensed)	=	2·355	6·43 %
Sulphur dioxide (SO_2)	=	0·0325	0·009 %
Nitrogen (N_2)	=	27·9566	76·25 %
		36·7091	100·00 %

Total volume of air is 7·397 + 27·9 = 35·297 mols. As 1 mol. equals 22·412 litres, the amount of air required for 100 grams of the coal under consideration would be 22·412 × 35·297 = 791 litres, or $\frac{791}{28 \cdot 375} = 27 \cdot 9$ cu. ft.

It will be noted that the maximum theoretical quantity of CO_2 in waste gases when burning this given class of coal is not as high as 20 %, being only 17·311 %.

The quantity of air required for the complete combustion of 1 lb. of this coal can be ascertained thus :—

1 lb. = 453·5 grams, so the air required for 1 lb. of coal will be 27·9 × 4·535 = say 126 cu. ft. Or, again, 1 lb. of air, if at 62° F., has a volume of 12·4 cu. ft. at atmospheric pressure, and the weight of air for 1 lb. of coal instead of 100 grams of coal will be $\frac{126}{12 \cdot 4} = 10 \cdot 16$ lb.

The theoretical amount of air required for combustion and the composition of the products of combustion can be calculated in this way for any class of coal of which the *complete* chemical analysis is known.

With hand firing or stoker firing there is always present a greater or less amount of excess air. If, for the sake of argument, there should be at times 150 % excess of air beyond that required (100 %) for the coal considered in the previous example, we should have :—

$$\left.\begin{array}{ll}\text{Volume of air supplied} & = 126 \times 2 \cdot 5 = 315 \text{ cu. ft.} \\ \text{Weight ,, ,, ,,} & = 10 \cdot 16 \times 2 \cdot 5 = 25 \cdot 4 \text{ lb.}\end{array}\right\} \text{per lb. of coal.}$$

The composition of the products of combustion when 150 % excess of air is supplied will be as follows :—

Amount of air theoretically required, as previously determined, is 35·297 mols.; 150 % excess of this would be 35·297 × 1·5 = 52·9 mols. (35·297 representing the volume for 100 % air supply).

Of this 52·9 mols., 20·91 % is oxygen and the rest nitrogen, so 52·9 × 20·91 % = 11·07 mols. of oxygen and 52·9 — 11·07 = 41·83 mols. of nitrogen.

By the addition of these totals to the total volumes arrived at for 100 % air supply, we then have the following composition of products of combustion :—

		Mols.	Percentages.
Carbon dioxide (CO_2)	=	6·35	7·097 %
Water vapour (H_2O) (uncondensed)	=	2·355	2·63 %
Sulphur dioxide (SO_2)	=	0·0325	0·003 %
Nitrogen (N_2)	=	69·7866	77·92 %
Oxygen (O_2)	=	11·07	12·35 %
		89·5941	100·00 %

It will thus be seen that with 150 % excess of air—a not infrequent occurrence for hand or even stoker firing—the CO_2 content in the waste gases is reduced to a little under half the theoretical figure, 7·097 % instead of 17·311 %. Excess of air supply is even more evident as the percentage of CO_2 is further reduced. This is very clearly shown in the following table, in which corresponding figures are given for excess of air and the CO_2 contained in the products of combustion of pure carbon :—

Percentage CO_2.		Percentage Excess Air.
15	(Approx. conditions approaching pulverised coal firing)	38
14		47
13		59
12		72
11		88
10	(Approx. normal conditions for mechanical stoker firing)	107
9		130
8	(Approx. normal conditions for hand firing)	159
7		196
6		245
5		314
4		417
3		590
2		935
1		1970

It should be stated that this table is based on pure carbon, whereas coal consists of only 80 % or less of carbon, so that the table is not strictly accurate for coal. It serves, however, to show the general relation between the CO_2 content of waste gases and the amount of excess air when burning fuel consisting largely of carbon, and for this reason it will be found useful as a general guide.

When there is a heavy excess of air not only do the products of combustion become diluted with useless gases, but the temperatures reached under these conditions fall very rapidly. This can be seen by reference to the curves shown in Fig. 6, which shows the rapid fall in temperatures due to the excess of air and preventable loss due to this cause.

Inset are tables of figures relating to normal hand-firing, mechanical stoker-firing, and pulverised coal-firing conditions, and, in order to make the intrinsic values of these determinations stand out clearly, the corresponding costs for coal used under the three systems are stated for 100,000 tons of coal burned; the price of coal being taken at 25*s*. per ton (2240 lb.). For a higher cost of coal the relative values for fuel wasted in every 100,000 tons of coal consumed will, naturally, be increased.

Loss introduced by the formation of CO need not here be further referred to, except that it will be well to remember that every cubic foot of CO will produce on combustion 340 B.Th.U., and, if CO escapes to the flues unburned, this heat value is lost for every cubic foot unconsumed.

Reduction in Excess of Air for Pulverised Fuel Firing.

With hand firing or stoker firing one can, for the several reasons mentioned,

only approximately reach ideal combustion conditions, even when the utmost skill is used, and, in consequence, should there be a high CO_2 content, there will always be more or less CO and free oxygen in the waste gases, together with unburnt hydrocarbons.

With pulverised coal firing the variable coal factors responsible for inefficient combustion can be eliminated, and the control of fuel and air supplies readily effected so that high combustion efficiencies result; and it should be possible, theoretically, to eliminate all the losses due to excess of air, insufficient air, improper mixing of free oxygen, unburnt fuel, etc., etc.

In practice the maximum efficiency of combustion is closcly approached. For

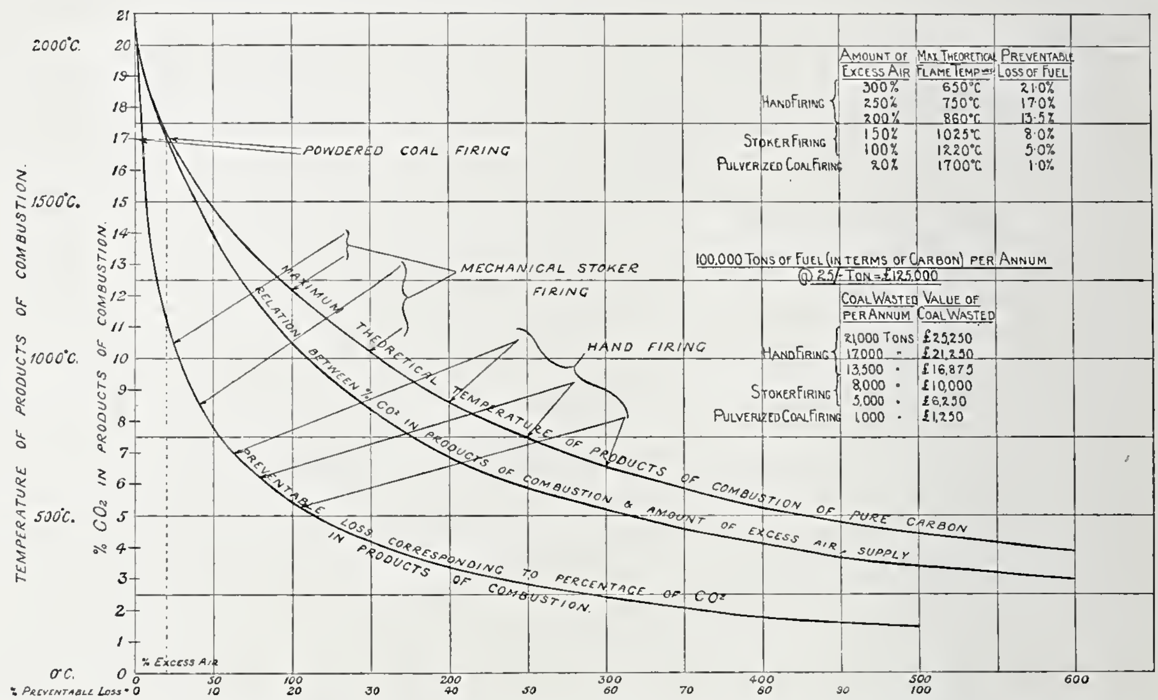


FIG. 6.—Curves showing maximum Theoretical Flame Temperatures, Loss of Heat due to Excess Air, and Comparative Values of Preventable Loss of Fuel for Hand Firing, Mechanical Stoker, and Pulverised Coal Firing.

instance, the amount of excess air does not usually exceed 20 %, which by reference to the curve for preventable loss, Fig. 6, means an actual fuel wastage of undcr 5 %.

When fuel is pulverised it becomes impossible for ash to form an oxygen-proof coating round the combustible, and there can be no wastage, due to small pieces of unburnt fuel dropping through the fire- and grate-bars, neither is there loss caused by unconsumed fuel raked out with the ashes whilc cleaning the fires.

In hand or stoker firing all these losses occur simultaneously and may amount to very serious proportions. It is no exaggeration to say that the majority of furnace ashes and clinkers contain anything from 25 % to 35 % of unburnt fuel.

If, for instance, the clinker should contain 20 % of carbon, when the lump coal contains only 10 % of ash, an actual loss equivalent to 2 % of the coal as fired is taking place, an item amounting to £75 per annum on 2500 tons of coal costing 30*s*.

per ton. Furthermore it means a weight of 50 tons carried to the boiler and carted away again for no useful purpose whatever. The ashes and clinker from a pulverised coal-fired furnace should not contain more than $\frac{1}{2}$ % to 1 % of unburnt fuel.

There is another source of loss to bear in mind under hand-firing or stoker-firing conditions. This is the formation of soot upon the relatively cool heat-receiving surfaces of steam boilers, stills, evaporating pans, melting pots, etc. With pulverised coal firing there is no soot or smoke. Pure soot is almost pure carbon, but the loss due to considering soot as so much unburnt carbon or fuel is a very negligible amount even in the worst cases. Soot is, however, such an excellent heat insulator that a coating one-sixteenth of an inch thick will reduce the effectiveness of a heating surface by some 25 %. Soot nearly always contains a certain amount of tarry matter sufficient to cause it to adhere to a cool boiler surface, and upon an initial thin coating a heavy accumulation rapidly builds up.

Calculation of Efficiency of Furnaces (Sources of Loss).

The only portion of the heat value of fuel which is of real moment to a fuel user is that portion which is converted into useful work. The overall thermal efficiency, or the relative amounts of heat wasted and utilised, in each instance are, therefore, of supreme importance.

The exact meanings of generic and specific thermal efficiency should be thoroughly understood. In the case of a metal-melting furnace, a certain and definite amount of heat is required to melt the metal and bring it to casting temperature. Also, in the case of a steam boiler, known quantities of water and of water vapour are raised to a predetermined temperature. In a blast furnace there is a combination of definite chemical reactions evolving and absorbing heat, and there is a definite weight of metal to be raised to a known temperature. In all such cases the "specific efficiency" of the thermal operation can be ascertained. On the other hand, when a given temperature has to be maintained for a given time, and the bulk of the heat supplied is lost in the waste gases and by radiation, it then becomes possible only to speak of "generic," or "comparative," efficiencies.

Examples of the latter occur in an annealing furnace where a red heat is maintained for several days, or in a puddling furnace at the stage where the iron is maintained at a given temperature after the melting operation has been completed. In these and many other similar cases the material under heat treatment absorbs little or no additional heat during a long period of the complete operation. In such cases a comparison of the amount of heat supplied and the amount of heat remaining in the material at the end of the operation does not indicate any measure of the efficiency of the furnace. It is of interest or use to compare the general efficiency of one furnace against another only if of similar type, but perhaps fired under a different system or embodying a variation in design. One of two similar furnaces may take twice as long or twice as much fuel as the other to effect the same result. When it has been ascertained that the one furnace is working at a lower efficiency than the other, it then becomes necessary to investigate the sources of waste which are responsible for this lower efficiency.

Consider the case of a continuous reheating furnace in which five tons of steel

billets per hour are heated to 1150° C. (2100° F.) and where the average quantity of pulverised coal burned in practice is 200 lb. per ton of steel or 1000 lb. of coal in all for the five tons of steel, or, say, 454 kilos of good quality coal per hour. The overall thermal efficiency of such a furnace is expressed by the relation between the amount of heat in the billets leaving the furnace and the amount of heat in the fuel supplied to the furnace. This is a case where the " specific thermal efficiency " can be stated.

The specific heat of steel at 1150° C. may be taken as 0·1675. The temperature of the billets entering the furnace will be assumed to be 20° C. (68° F.), so that the temperature range of the operation is 1150° − 20° C. = 1130° C.

The total weight of steel per hour is 5 × 2240 = 11,200 lb. =

$$11{,}200 \div 2{\cdot}204 = 5081 \text{ kilos.}$$

Then, 5081 × 1130° × 0·1675 = 961,000 Calories in steel leaving the furnace per hour.

We may assume the use of a coal of the same composition as previously dealt with in the chapter on combustion, as follows :—

Total carbon = 76·38 %; hydrogen = 4·71 %; oxygen = 5·70 %; nitrogen = 1·59 %; sulphur = 1·04 %; ash = 10·58 %

having a calorific value of 7702 Calories per kilo or 13,860 B.Th.U. per lb.. Then using 1000 lb., or 454 kilos, of coal per hour in the dry pulverised state, the heat supplied to the furnace would be : 454 × 7702 = 3,496,000 Calories per hour, which gives $\frac{961{,}000 \times 100}{3{,}496{,}000} = 27{\cdot}48\ \%$ as the overall efficiency. This is a particularly good practical result, although 72·55 % of the fuel supplied to the furnace is wasted. It is then interesting to know how and where the 72·55 % of the heat is lost. The amount of heat lost is 3,495,000 × 72·55 % = 2,535,000 Calories per hour.

To know how and where the 72·55 % of the heat is wasted, a full analysis of the waste gases must be obtained, and the combustion conditions be determined in the manner explained at p. 77.

Under good working conditions with pulverised fuel there will be usually an excess air supply of about 25 %, and we will, therefore, assume that such is the case in this instance. We can then determine the composition of the waste gases to be as follows :—

	Mols.	Percentage.
Carbon dioxide (CO_2) . . .	6·365	13·96 %
Uncondensed water (H_2O) . .	2·355	5·173 %
Sulphur dioxide (SO_2) . .	0·0325	0·007 %
Nitrogen (N_2)	34·9316	76·76 %
Oxygen (O_2)	1·865	4·1 %
	45·5491	100·00 %

It is necessary to know the temperature at which the waste gases leave the furnace, and this will be assumed to be 600° C., although this is higher than would be the case in a modern continuous type of furnace.

From a table of thermal capacities of gases per molecular volume or mol, such as is given at p. 403, we can readily calculate the amount of heat in the above gases at 600° C. to be :—

Carbon dioxide	(CO_2)	$= 6{\cdot}365 \times 6{\cdot}44$	$= 41$
Water	(H_2O)	$= 2{\cdot}355 \times 5{\cdot}87$	$= 13{\cdot}8$
Sulphur dioxide	(SO_2)	= Negligible	
Nitrogen	(N_2)	$= 34{\cdot}9316 \times 4{\cdot}31$	$= 151$
Oxygen	(O_2)	$= 1{\cdot}865 \times 4{\cdot}31$	$= 8$
			213·8 Calories.

As the above represents the heat lost from 100 grams of coal, the heat from 1 kilo would be 2138 calories. The amount of coal used is 454 kilos per hour, so that the heat carried away in the products of combustion of this amount of coal at 600° C. will be : $2138 \times 454 = 970{,}652$ Calories. This represents 38·3 % of the total loss of 2,535,000 Calories occurring in this furnace.

A second loss will be in the ashes and slag discharged from the furnace. The ash amounts to 10·58 % of the fuel, or : $454 \times 10{\cdot}58\ \% =$ say, 48 kilos per hour. A certain percentage of this ash in the form of fine dust is discharged with the waste gases, the remainder accumulating on the bottom of the combustion chamber and the furnace.

Assume for the purpose of calculation that 50 % of the ash is discharged up the stack at 600° C. (same temperature as waste gases) and 50 % is removed from the combustion chamber periodically at a temperature of 800° C. At 800° C. the average specific heat of ash and slag would be 0·30 and at 600° C. 0·26. The actual temperature ranges are, therefore, 780° C. and 580° C. respectively, if it is assumed that the coal enters the furnace at a temperature of 20° C. Loss of heat in the ash will then be :—

Loss in combustion chamber of furnace	$= 227 \times 0{\cdot}30 \times 780° = 53{,}200$ Calories.
Loss at exit	$= 227 \times 0{\cdot}26 \times 580° = 39{,}500$,,
	Total = 92,700 Calories lost in ash.

The total heat loss which occurs in the ashes is, therefore, equal to 3·65 %. The balance of some 1,471,648 Calories is lost by conduction and radiation through and from the furnace walls, and in a measure by absorption of heat by the water-cooled skid pipes. Were other factors, such as design of furnace, velocity of gases, etc., known, it would then be possible to further subdivide the balance of radiation losses.

For all practical purposes the main heat losses are represented by the calculations

reviewed above, and for a furnace of this description these are generally of the order given, namely :—

Heat usefully applied	27·48 %
Heat lost in waste gases	38·30 %
Heat lost in ash and slag	3·65 %
Heat lost by radiation, etc. . . .	30·57 %
	100·00 %

Pulverised fuel firing requires but 20 % excess of air, and for average practice 25 % has been assumed; this is much below the 100 % and 200 % of hand-firing practice, and for solid fuel firing cannot be further reduced.

Again, the heat in the ashes is trifling compared with the losses due to unconsumed carbon in clinker formed on grates or loss through fire bars.

The large amount of heat passing away in waste gases should be used to heat a steam boiler, which, if operating at 65 % efficiency, would evaporate about 2500 lb. of water per hour. By this means the loss of heat in the waste gases would be reduced from 38·30 % to about 13 % of the total heat supplied to the furnace.

The radiation loss from furnace walls can be greatly reduced by the application of a suitable coating of non-conducting material over the brickwork. By this means it should be possible to reduce the heat lost at this point to 10 % or 15 % of the total heat applied, with a corresponding reduction in the fuel consumption of the furnace when doing the same work. An approximate analysis of the heat distribution in a furnace should always be taken, for this constitutes a very valuable guide as to the possibility of increasing its overall efficiency.

The Heat Conductivity of Refractory Bricks has been recorded by Sir Robert Hadfield, F.R.S., in his 1918 address to the Society of British Gas Industries, and by permission the graph (Fig. 7) has been reproduced.

In the case of an annealing oven or similar application, for which the specific efficiency cannot be stated, the general efficiency of the actual furnace or firing conditions can be investigated and steps taken to remove or reduce recorded losses.

The first essential proceeding in connection with any fuel application is to investigate the primary combustion conditions in the light of fuel and waste gas analyses, and establish the maximum theoretical heat value of the fuel, to tabulate the various ascertainable losses, and to see whether the balance representing heat dissipated by radiation, etc., cannot be further reduced.

The exit temperatures for high heat furnaces are also relatively high, so that furnaces of this description cannot be operated to the same degree of efficiency as low-temperature furnaces, unless the heat contained in waste gases is subsequently utilised.

When there is considerable heat leaving a furnace, an attempt always should be made to make use of the hot waste gases. Failing this, it is seldom possible to secure an overall thermal efficiency above 4 % or 5 % for high-temperature furnaces.

It can be roughly assumed that low-temperature furnaces operate below 1200° C. and high-temperature furnaces at, as a rule, considerably above this figure.

Another source of economy is to increase the flame temperature by using some of the heat in the waste gases to preheat the air required for combustion.

The steam boiler presents another case of " specific " thermal efficiency.

Two factors of primary importance are here presented, namely, the heat supplied to the boiler in the fuel and the heat in the steam leaving the boiler. In this case, owing to the comparatively low temperature of steam, including superheated steam, it is possible to obtain relatively high overall thermal efficiencies.

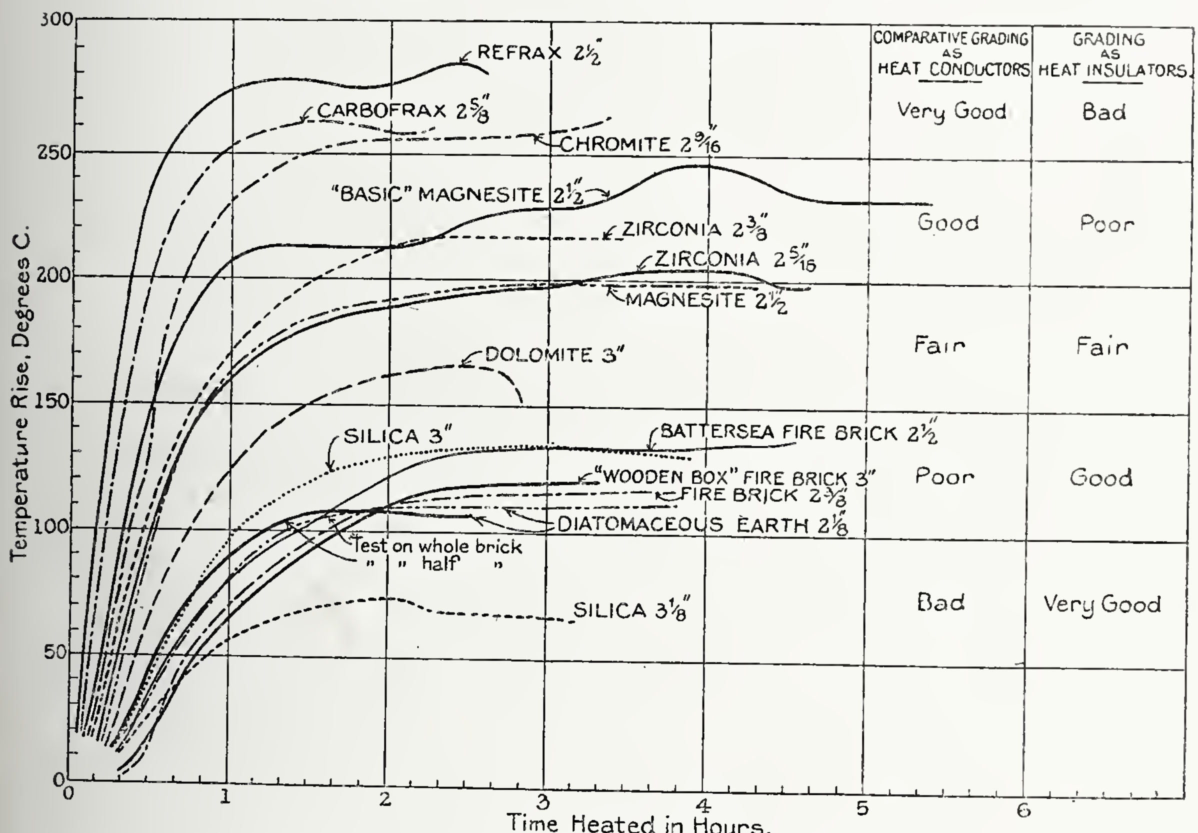


FIG. 7.—Heat Conductivity of Refractory Bricks.

The Gas World (*Sir Robert Hadfield*, 1918 *Address to Society of British Gas Industries*).

Calculation of Efficiency of Water Tube Boiler Plant (Sources of Loss).

Consider a " specific " case, say of a modern water-tube boiler with a normal output of 18,000 lb. of steam per hour, fired with pulverised coal. It is desired to determine the overall thermal efficiency of such a boiler when working at or near full load.

The value of an efficiency test on a boiler lies largely in the duration of the test, for, as a rule, it is a comparatively easy matter to maintain " high efficiency " conditions for one or two hours, whereas this period of test in no way represents the day in and day out average working conditions. Therefore, from the technical, and even the practical point of view, a boiler test should extend over at least twenty-

four hours' continuous running. Even so, working results for a month for hand-fired or stoke-fired boilers would fall short of test results, but with pulverised fuel firing there is no reason why test results should not be maintained indefinitely. Assume that the pulverised fuel in this case, as it enters the burner, has the following composition :—

Carbon 73·6 %; hydrogen 5·3 %; nitrogen 1·7 %; sulphur 0·75 %; oxygen 10·00 %; moisture 0·60 %; ash 8·05 %,

the calorific value being 13,450 B.Th.U. per lb. or 7,470 Calories per kilo. By making calculations similar to those presented in the case of the fuel used for the reheating furnace efficiency test, it will be found that products of combustion from 100 grams of this coal can be obtained from the analysis of the fuel, assuming that the fuel is burnt under ideal conditions in air, thus :—

	Mols.	Percentage.
Carbon dioxide (CO_2)	6·13	17·063%
(Uncondensed) water vapour (H_2O) .	2·6833	7·39 %
Sulphur dioxide (SO_2)	0·0234	0·007%
Nitrogen (N_2)	27·1476	75·54 %
	35·9843	100·00 %

The volume of air required for combustion is 27·087 + 7·1659 = 34·2529 mols.

As previously mentioned, 1 mol. of any gas occupies 22·412 litres; the amount of air required for 100 grams of the coal under consideration will then be :—

$$34{\cdot}2529 \times 22{\cdot}412 = \text{say, } 765 \text{ litres, or, } 7650 \text{ litres per kilo.}$$

Or, alternatively, taking the composition of the coal as above and consulting the tables given at p. 401; the following results are obtained :—

1 lb. of carbon requires 2·667 lb. of oxygen for its combustion, producing 3·667 lb. of carbon dioxide; therefore, 0·736 lb. of carbon will require 2·667 × 0·736 = 1·965 lb. of oxygen to form 0·736 + 1·965 = 2·701 lb. of CO_2.

Similarly, 1 lb. of hydrogen combines with 8 lb. of oxygen to form 9 lb. of water vapour; therefore, 0·053 lb. of hydrogen combines with 8 × 0·053 = 0·424 lb. of oxygen to form 0·053 + 0·424 lb. = 0·477 lb. of water vapour.

Again, 1 lb. of sulphur combines with 1 lb. of oxygen to form 2 lb. of sulphur dioxide; therefore 0·0075 lb. of sulphur will combine with 0·0075 lb. of oxygen to form 0·0075 + 0·0075 = 0·0150 lb. of sulphur dioxide.

The amount of oxygen required is, therefore :—

For carbon . . .	1·965	lb.
,, hydrogen . . .	0·424	,,
,, sulphur . . .	0·0075	,,
	2·3965	lb.

The coal contains 0·10 lb. of oxygen, so the net amount of oxygen required from the air is 2·3965 — 0·10 = 2·2965 lb. This is accompanied by 2·2965 × 3·32=

7·62 lb. of nitrogen. The coal also contains 0·006 lb. of water, which must be added to the 0·477 lb. of water produced by the hydrogen, or a total of 0·483 lb. water.

The products of combustion from 1 lb. of coal will then be :—

	By Weight.	By Volume at N.T.P.
Carbon dioxide	2·701 lb.	22·05 cu. ft.
Water	0·483 ,,	9·58 ,,
Sulphur dioxide	0·015 ,,	0·90 ,,
Nitrogen	7·62 ,,	98·00 ,,
Total	10·819 lb.	130·53 cu. ft.

which gives a percentage composition closely in agreement with that previously determined, viz :—

Carbon dioxide	(CO_2) . . .	17·0 %
Water vapour	(H_2O) . . .	7·45 %
Sulphur dioxide	(SO_2) . . .	0·007%
Nitrogen	(N_2) . . .	75·543%
		100·00 %

The amount of oxygen required has been determined as 2·2965 lb. net, which oxygen is accompanied by $2{\cdot}2965 \times 3{\cdot}32 = 7{\cdot}62$ lb. of nitrogen. Or, total weight of air is $2{\cdot}2965 + 7{\cdot}62$ % $= 9{\cdot}9165$ lb., and if air be taken as 12·39 cu. ft. per lb. the required amount of air will be 122·5 cu. ft. per lb. of coal.

Either of these methods of arriving at the composition of the waste gases and the amount of air for combustion may be used, but the former method of working in metric units and mols. is both quicker and easier.

If a maximum efficiency is to be reached it will be necessary to clean the inside of all heating surfaces from scale and the outside of these surfaces from soot, dust or slag.

A question of extreme importance is air leakage through cracks and joints in the boiler setting, because any air thus leaking into the combustion chamber or flues reduces the overall thermal efficiency of the unit. All such cracks and joints should be located and stopped up. The easiest way to locate them is by the aid of a candle or open-flame lamp while the boiler is in operation and under draught. The flame, if held near any suspected joint, will be drawn into the setting wherever an open crack exists.

The essential measurements to be made in a boiler test are the amount of fuel used, the amount of water evaporated, the temperature of the water entering the heating system, the temperature of the steam leaving the stop valve, the pressure of the steam and the calorific value of the fuel. It is also helpful and desirable to record the temperature of the waste gases leaving the unit under test, the composition of the flue gases, the weight of ash from the combustion chamber, the weight of ash and dust in the flues, the temperature of the boiler-room, the temperature of the

water leaving the economiser and entering the boiler, the temperature of the ash discharged from the ashpit, the draught at the furnace and at the chimney and the amount of unburnt carbon in the ash.

Assuming that the test has been concluded and the various readings recorded, the average results should be put down as indicated by the following hypothetical case :—

Test of Boiler No.
Date
Station
Test No.
Total duration of Test—10 hrs. 0 min.
Type of Boiler—B. & W. Water Tube type.
Normal Rating—18,000 lb. per hour.
Method of Firing—Pulverised Coal.

		As Fired.	Dry Basis.
Analysis of fuel	Carbon	73·6 %	74·10 %
	Hydrogen	5·3 %	5·333%
	Nitrogen	1·7 %	1·713%
	Sulphur	0·75%	0·754%
	Oxygen	10·00%	10·040%
	Moisture	0·60%	—
	Ash	8·05%	8·06 %

Calorific value	13,450 B.Th.U. per lb. as fired.
Total weight of coal as fired	22,200 lb.
Total weight of water evaporated	185,500 lb.
Average steam pressure	165 lb. per sq. in. (gauge).
Average final steam temperature	523° F.
Average temperature of feed water	112° F.
Average temperature of water entering boiler from economiser	242° F.
Weight of ash recovered from combustion chamber	1070 lb.
Average amount of combustible left in ash	5·6 % (by analysis).
Boiler-room temperature	70° F.
Analysis of waste gases	CO_2 = 14·06 % CO = 0·72 % O_2 = 4·42 %
Average temperature of waste gases	380° F.
Average temperature of combustion chamber	2450° F.
Average temperature of ashes leaving furnace	1260° F.
Specific heat of ash and slag (by experiment)	0·280.

From the results recorded above the distribution of the heat may be arrived at as follows :—

1. Heat absorbed by boiler, economiser and superheater : From standard steam tables it will be found that 1196 B.Th.U. are required to heat 1 lb. of water at 32° F.

to steam at 165 lb. per sq. in. gauge pressure (= 180 lb. absolute). Feed water is supplied in this case at 112° F., that is to say, it contains 112 — 32 = 80 B.Th.U. per lb. Total heat to be supplied to form saturated steam at 165 lb. pressure is then: 1196 — 80 = 1116 B.Th.U. per lb. The normal temperature of steam at 165 lb. gauge pressure is 523° F. or 523 — 373 = 150° F. of superheat.

From superheated steam tables it will be found that 83·8 B.Th.U. are required to superheat 1 lb. of steam at 150° F. at 165 lb. gauge pressure. The total heat in 1 lb. of steam under the test conditions under consideration is, therefore, 1116 + 83·8=1199·8 B.Th.U., or say, 1200 B.Th.U. per lb. The total amount of fuel supplied to the furnace was 22,200 lb., containing 22,200 × 13,450 = 298,590,000 B.Th.U. The ash, however, contained 5·6 % of carbon, which is 5·6 × 8·05 % (see fuel analysis) = 0·45 % of the fuel supplied to the furnace, or, 22,200 × 0·45 % = 100 lb.

1 lb. carbon, when completely burned, gives out 14,544 B.Th.U., so that 100 lb. carbon represent 1,454,400 B.Th.U. Therefore the net heat generated in furnace is 298,590,000 — 1,454,400 = 297,135,600 B.Th.U.

The heat absorbed by the economiser, boiler and superheater is then :—

$$\frac{222{,}600{,}000}{297{,}135{,}600} = 74{\cdot}9\ \%\ \text{of the heat generated.}$$

or :—

$$\frac{222{,}600{,}000}{298{,}590{,}000} = 74{\cdot}60\ \%\ \text{of the heat supplied in the fuel.}$$

2. Heat loss by evaporation of moisture in the fuel: The moisture in the fuel is, of course, converted into steam, which is superheated and finally escapes at the same temperature as the waste gases. To raise 1 lb. water from 70° F. (the temperature of boiler-room and fuel) to 212° F. requires 212 — 70 = 142 B.Th.U. To convert this water at 212° F. to steam at 212° F. requires 970 B.Th.U. The average specific heat of steam over the range 212°–380° F. may be taken at 0·47, so that heat for raising saturated steam to 380° F. is (380–212) 0·498 = 83·6 B.Th.U., say, 84 B.Th.U.

We then have: 142 + 970 + 84 = 1196 B.Th.U. per lb. at 380° F. 1 lb. of coal contains only 0·006 lb. of moisture (see fuel analysis) or 1196 × 0·006 = 7·176 B.Th.U. per lb. of coal burnt is lost in the moisture passing out with waste gases.

3. Loss in steam formed by combustion of hydrogen in fuel: The fuel contains 0·053 lb. of hydrogen per lb., thus forming 0·053 × 9 = 0·477 lb. of water vapour.

As above, the heat in 1 lb. water at temperature of waste gases is 1196 B.Th.U. or 1196 × ·477 = 570 B.Th.U. per lb. coal burnt and lost in the moisture produced by the burning of the hydrogen.

4. Heat lost in the dry flue gases: The loss in the water in the flue gases formed by the burning of hydrogen and evaporation of moisture in the fuel having been dealt with, the loss in the "dry" gases only may be considered.

The analysis of flue gases was found to be :—

CO_2 14·06 %; CO 0·72 %; O_2 4·42 %; N_2 80·8 % (by difference neglecting SO_2) The ratio of the air supplied to the air theoretically required may be found from the formula :—

$$R = \frac{N_2}{N_2 - 3{\cdot}782\,(O_2 - \frac{1}{2}CO)}$$

that is, =

$$\frac{80{\cdot}8}{80{\cdot}8 - 3{\cdot}782\left(4{\cdot}42 - \frac{0{\cdot}72}{2}\right)} = 1{\cdot}26 \text{ to } 1.$$

or 26 % excess air.

The amount of air required for the coal under consideration was found to be 9·9165 lb. per lb. fuel. Therefore air supplied was 9·9165 × 1·26 = 12·5 lb.

Weight of flue gases is weight of fuel plus weight of air supplied or 1 + 12·5 = 13·5 lb. per lb. fuel burnt. The specific heat of flue gases of average composition at the temperature under consideration may be taken as 0·24. The temperature range is 380 — 70° F. = 310° F.

Or, 13·5 × 0·24 × 310 = 1004 B.Th.U. lost in dry flue gases.

5. Lost in unburnt CO : As CO (carbon monoxide) is a combustible gas it follows that any CO in the flue gases represents undeveloped heat which is wasted. The heat lost in this manner may be found from the formula :—

$$\text{Loss in B.Th.U. per lb. fuel} = C\,(10{,}150)\,\frac{CO}{CO_2 + CO}$$

or,

$$0{\cdot}736 \times 10{,}150 \times \frac{0{\cdot}72}{14{\cdot}06 + 0{\cdot}72} = 362 \text{ B.Th.U.}$$

per lb. fuel burnt.

6. Lost in carbon in ashes : In item (1) it has already been shown that the carbon in the ashes represents 0·45 % of the carbon in fuel, and that 1 lb. carbon develops 14,544 B.Th.U. when completely burnt. Heat lost in this way from 1 lb. carbon will thus be : 14,544 × 0·0045 = 65 B.Th.U.

7. Lost in ash dust passing out with flue gases : The total amount of ash from the coal used was, according to analysis, 22,200 × 8·05 % = 1788 lb. Of this, 1070 lb. was recovered from the combustion chamber, leaving 1788 — 1070 = 718 lb. passing out with the waste gases at 380° F. The average specific heat of the ash and slag was determined by experiment as 0·28, or :—

$$\frac{(380° - 70°)\,718 \times 0{\cdot}28)}{22{,}200} = \begin{cases} 2{\cdot}8 \text{ B.Th.U. per lb. coal fired lost in ash dust. Say,} \\ \qquad 3 \text{ B.Th.U.} \end{cases}$$

8. Lost in ashes and slag removed from combustion chamber : 1070 lb. of ash and slag was removed from the combustion chamber at the end of the test at an observed temperature of 1260° F., or :—

$$\frac{(1260° - 70°)\,1070 \times 0{\cdot}28}{22{,}200} = 16 \text{ B.Th.U. per lb. coal fired lost in ash and slag.}$$

In addition to the above losses, a small amount of heat would be required for heating up the moisture in the air supply, but its amount is negligible.

A heat balance may now be prepared from the results arrived at, as follows :—

DISTRIBUTION OF HEAT PRODUCED BY COMBUSTION OF 1 LB. OF FUEL.

Item.	B.Th.U.	Percentage of Total Heat supplied in 1 lb. of fuel.
1. Absorbed by economiser, boiler and superheater	10,035	74·65 %
2. Lost in evaporated moisture from fuel	7	0·0005%
3. Lost in steam formed by combustion of hydrogen	570	4·24 %
4. Heat lost in dry flue gases	1,004	7·487 %
5. Lost in unburnt CO	362	2·69 %
6. Lost in carbon in ashes	65	0·4833%
7. Lost in ash dust in waste gases	3	0·0002%
8. Lost in ash and slag from combustion chamber	16	0·119 %
9. Lost by radiation and unaccounted for	1,388	10·33 %
	13,450	100·00 %

Item (1) is really the only one of value to the steam user. A hypothetical case has been taken and an efficiency figure arrived at which would not be accepted for pulverised coal firing.

Items (2), (3) and (4) are directly dependent on the temperature of the waste gases passing to the stack, which in this case is 380° F. For a boiler operating under natural draught, as assumed in this case, it would be impossible to reduce this temperature by any appreciable amount and at the same time to maintain sufficient draught for efficient operation. These losses, amounting to 11·7275%, must, therefore, be accepted.

The loss due to unburnt CO, item (5), is a preventable one, depending entirely on the efficiency of combustion. It has been shown that 26 % excess air was supplied during the test according to the flue gas analysis. The presence of CO and O_2 in the flue gases therefore suggests incomplete mixing of the fuel and air in the combustion chamber, and steps should be taken to remedy this by any means found necessary.

Item (6) is, comparatively, very small, and no reduction in this direction can be reasonably expected, the result already obtained being very good.

The loss of heat in the ash dust, ash and slag, items 7 and 8, is a negligible amount, not worth making any attempts to reduce in any way.

Item (9), representing loss by radiation, is by far the greatest of the preventable losses, and ought not to amount to more than 3 %. It proves that immediate steps should be taken to lag efficiently any of the surfaces of the boiler exposed to the atmosphere, and, if necessary, increase the thickness of the brickwork, or apply an insulating covering to the outer surface of the boiler setting. If by this means the radiation losses were reduced to 3 %, it would mean that the heat contained in 7 % of the fuel previously lost would then be usefully absorbed by the boiler, thus increasing its output, or, conversely, for equal boiler output 7 % less fuel would be used. The importance of this will be seen when it is realised that, by making this saving, an economy of 525 tons of coal per annum would be the result in this case.

It will, therefore, be seen that thorough efficiency tests of a boiler plant at regular intervals are of real value if intelligently interpreted. But the necessity for thoroughness and impartial action and judgment in making a boiler test cannot be overestimated, because there are so many ways in which the figures obtained can readily be influenced in the desired direction, if such a desire exist.

The above case has been presented and the calculation based entirely upon British Thermal Units. In order to emphasise the easier manner in which calculations can be made by using Metric Units, another hypothetical boiler test may be taken.

Steam Boiler Test.

Test of Boiler No.
Date.
Station.
Test No.
Total duration of Test—20 hrs. 0 min.
Type of Boiler—Stirling Water Tube type.
Normal Rating—10,000 kilos per hour.
Method of Firing—Pulverised Coal.

		%
Analysis of fuel as fired.	Carbon	81·64
	Hydrogen	4·81
	Nitrogen	1·26
	Sulphur	1·30
	Oxygen	4·31
	Moisture	0·93
	Ash	5·75

Calorific value	8,050 Calories per kilo.
Total weight of coal fired during test	21,300 kilos.
Total weight of water evaporated	210,500 kilos.
Average steam pressure	14 kilos per sq. cm. (absolute).
Average final steam temperature	272° C.
Average temperature of feed water	52° C.
Average temperature of water entering boiler from economiser	110° C.
Weight of ash recovered from combustion chamber	800 kilos.
Average amount of carbon left in ash	6·5 % (by analysis).
Boiler-room temperature	20° C.
Analysis of waste gases	CO_2 14·8 %
	CO 0·89 %
	N_2 80·75 % (by difference).
	O_2 3·56 %

Average temperature of waste gases	200° C.
Average maximum temperature in combustion chamber	680° C.
Average temperature of ashes leaving furnace .	560° C.
Specific heat of ashes and slag	0·290 (by experiment).

From the foregoing figures the distribution of the heat losses may be investigated as follows :—

1. Heat absorbed by economiser, boiler and superheater : The specific heat of water over the range 50°–100° C. may be taken as unity for practical purposes (actually it is 1·015 at 100° C.).

To heat 1 kilo of water from 52° C. (the temperature entering economiser) to 100° C. requires $100 - 52 = 48$ Calories. The latent heat of vaporisation of water at 100° C. is 537 Calories. The steam thus produced has to be heated to 272° C., that is, $272 - 100 = 172°$ C. range.

The specific heat of steam over the range 100° to 300 ° C. may be taken as $0{\cdot}42 + 0{\cdot}000185$ Calorie per kilo, or $0{\cdot}42 + (0{\cdot}000185 \times 272) = 0{\cdot}4704$; then : $0{\cdot}4704 \times 172° = 81$ Calories per kilo.

Total heat in steam at 272° C. is then : $48 + 537 + 81 = 666$ Calories.

The total amount of heat in the steam generated during the test is therefore : $666 \times 210{,}500 = 140{,}193{,}000$ Calories. The total amount of fuel supplied to the furnace was 21,300 kilos, containing $21{,}300 \times 8{,}050 = 171{,}465{,}000$ Calories. The percentage of the heat supplied absorbed by the water and steam in the boiler is $\frac{140{,}193{,}000}{171{,}465{,}000} = 81{\cdot}75$ %.

2. Heat lost by evaporation of moisture of fuel : The moisture in the fuel escapes at a temperature of 200° C. with the waste gases, after being raised from an initial temperature of 20° C., the temperature of the boiler-room. To raise 1 kilo of H_2O from 20° to 100° C. requires 80 Calories. The latent heat of vaporisation of water at 100° C. is 537 Calories. The superheat range is $200° - 100°$ C $= 100°$ C. The specific heat of steam over the range 100° to 300° may be taken as before as $0{\cdot}42 + 0{\cdot}000185$ Calorie per kilo, or $0{\cdot}42 + (0{\cdot}000185 \times 200) = 0{\cdot}457$; then : $0{\cdot}457 \times 100 = 45{\cdot}7$ Calories per kilo. Say, 46 Calories.

Total heat to raise steam to 200° C. from water at 20° C. is, therefore, $80 + 537 + 46 = 663$ Calories per kilo.

1 kilo of fuel contains 0·0093 kilo of moisture. Therefore, $663 \times 0{\cdot}0093 = 6{\cdot}16$ Calories per kilo of coal burnt are lost in the steam from moisture in the coal as fired.

3. Loss in steam formed by combustion of hydrogen in fuel : Hydrogen burns to form 9 times its own weight of water. The fuel contains 0·0481 kilo of hydrogen per kilo, thus forming $0{\cdot}0481 \times 9 = 0{\cdot}4329$ kilo of water. As above, the heat in 1 kilo of steam at 200° C. is 663 Calories, or, $663 \times 0{\cdot}4329 = 286$ Calories per kilo of coal burnt are lost in the water vapour produced by the burning of the hydrogen.

4. Heat lost in dry flue gases : The theoretical composition of the waste gases

when burnt in air and the amount of air required may be calculated in the manner previously described as follows :—

Coal analysis by weight is :—

	%	
Carbon	81·64	
Hydrogen	4·81	
Nitrogen	1·26	
Sulphur	1·30	Calorific value 8,050 Calories per kilo.
Oxygen	4·31	
Moisture	0·93	
Ash	5·75	

Carbon gives $\frac{81 \cdot 64}{12} = 6 \cdot 8$ mols. of CO_2.

Hydrogen gives $\frac{4 \cdot 81}{2} = 2 \cdot 405$ mols. of H_2O.

Sulphur gives $\frac{1 \cdot 30}{32} = 0 \cdot 0406$ mols. of SO_2.

The amount of oxygen required for combustion is :—

Carbon	6·8	mols.
Hydrogen	1·202	,,
Sulphur	0·0406	,,
Total	8·0426	,,

Of this amount $\frac{4 \cdot 31}{32} = 0 \cdot 1345$ mol. is available in the fuel.

The oxygen required from air is, therefore, $8 \cdot 0426 - 0 \cdot 1345 = 7 \cdot 9081$ mols. This is accompanied by $7 \cdot 9081 \times 3 \cdot 782 = 29 \cdot 95$ mols. of nitrogen. In addition there are $\frac{1 \cdot 26}{28} = 0 \cdot 0450$ mol. of nitrogen in the fuel. The total volume of nitrogen in the waste gases is, therefore : $29 \cdot 95 + 0 \cdot 045 = 29 \cdot 995$ mols.

Also there are $\frac{0 \cdot 93}{18} = 0 \cdot 0516$ mol. of water vapour from the moisture in the fuel, a total of 2·405 (see fuel analysis) $+ 0 \cdot 0516 = 2 \cdot 4566$ mols. of water vapour in waste gases.

The composition of the waste gases is, therefore :—

Carbon dioxide (CO_2) =	6·8	mols. =	17·3 %
Water vapour (H_2O) =	2·4566	,, =	6·237%
Sulphur dioxide (SO_2) =	0·0406	,, =	0·103%
Nitrogen (N_2) =	29·995	,, =	76·36 %
	39·2922	mols.	100·00 %

Or, if the water vapour is condensed and the sulphur dioxide neglected, as is almost always the case in practice, the composition of the waste gases may be given as follows: carbon dioxide = 18·5 %; nitrogen = 81·5 %.

The air required for combustion per 100 grams is :—

7·9081 + 29·95 = 37·8581 mols. or 378·581 mols. per kilo, or 378·581 × 22·32 = 8,460 litres or 8·46 m³. per kilo of coal burnt without excess air.

The composition of the waste gases by volume is found to be :—

$$CO_2 = 14{\cdot}8\ \%;\quad CO = 0{\cdot}89\ \%;\quad N_2 = 80{\cdot}75\ \%;\quad O_2 = 3{\cdot}56\ \%.$$

By the use of the formula : ratio of air used to air required by volume =

$$\frac{N_2}{N_2 - 3{\cdot}782\ (O_2 - \frac{1}{2}CO)}$$

it will be found that in this case the excess air supplied is lower than in the previous test considered, and amounts only to 20 %.

From the analysis of the fuel it can readily be calculated in the manner already given that the products of combustion from 1 kilo of fuel with 20 % excess air would be :—

$$CO_2 = 64{\cdot}15 \text{ mols.};\quad CO = 3{\cdot}864 \text{ mols.};\quad N_2 = 350{\cdot}04 \text{ mols.};\quad O_2 = 15{\cdot}433 \text{ mols.}$$

From tables of thermal capacities of gases such as are given at the end of this book it will be found that at 200° C. (the temperature of the waste gases) the thermal capacity of CO_2 is 1·85 Calories per molecular volume or mol., and of CO, N_2, and O_2 it is 1·39 Calories per mol.

The total thermal capacity of the above gases from 1 kilo of fuel is then readily calculated as 632 Calories, or $\frac{632}{8050}$ = 7·85 % of its thermal value. Alternatively, the mean specific heat of the various constituent cases can be determined and the heat absorbed over the temperature range under consideration determined. This would give a slightly more accurate result, although the method shown is sufficiently accurate for practical purposes.

5. Heat lost in unburnt CO (carbon monoxide) : The heat liberated by the combustion of 1 mol. of CO is 68·2 Calories. One kilo of fuel produces 3·864 mols. of CO, or, 68·2 × 3·864 = 264 Calories = 3·28 % of thermal value in fuel.

6. Lost in carbon in ashes : The unburnt carbon was found by analysis to be 6·5 % by weight of the ashes, or : 6·5 × 5·75 % = 0·373 % of the fuel as fired. Combustion of 1 kilo of carbon liberates 8080 Calories. 8080 × 0·00373 = 30·2 Calories per kilo fuel = 0·375 % of the thermal value of the fuel.

7. Lost in ash dust passing out with flue gases : The percentage of ash in the fuel was 5·75 % by analysis, or 21,300 × 5·75 % = 1223 kilos of ash and refuse would be left from the combustion of the coal used in the test. Of this 800 kilos was recovered from the combustion chamber, leaving 1223 — 800 = 423 kilos passing out with waste gases at 200° C.

Temperature range is 200° C. — 20° C. = 180° C. Specific heat 0·290, then total

heat loss is: $423 \times 180 \times 0{\cdot}29 = 22{,}600$ Calories. Or, per kilo of fuel $= \frac{22{,}600}{21{,}300}$ $= 1{\cdot}06$ Calories $= 0{\cdot}0132$ % of thermal value of fuel.

8. Lost in ashes removed from combustion chamber: Total heat lost is $800 \times 560^\circ \times 0{\cdot}29 = 153{,}200$ Calories. Loss per kilo fuel $\frac{153{,}200}{21{,}300} = 7{\cdot}2$ calories $= 0{\cdot}089$ % of thermal value of fuel.

From these figures a heat balance sheet may be set out as follows:—

Distribution of Heat in a Stirling Boiler of 10,000 Kilos per Hour Capacity.

Item.	Calories.	Percentage of calorific value of fuel as fired.
1. Heat absorbed by economiser, boiler and superheater	6580	81·75
2. Heat lost by evaporation of moisture in fuel	6	0·075
3. Lost in steam formed by combustion of hydrogen	286	3·56
4. Heat lost in dry flue gases	632	7·85
5. Lost in unburnt carbon monoxide (CO)	264	3·28
6. Lost in carbon in ashes	30	0·375
7. Lost in ash dust passing out with flue gases	1	0·013
8. Lost in ash and slag removed from combustion chamber	7	0·089
9. Lost by radiation, etc., and unaccounted for	244	3·008
	8050	100·00

Detailed consideration of these results gives the following conclusions:—

1. The heat usefully absorbed by the water and steam is a very high percentage of the total amount supplied, and is almost the maximum that can be obtained under normal working conditions, and only when solid fuel is applied in pulverised form.

2. The heat absorbed by evaporation of moisture in the fuel is a negligible amount.

3 and 4. These items are largely dependent on the final temperature of the waste gases, in the same way as item 2. The final temperature of the waste gases being only 200° C. in this case, very little, if any, reduction could possibly be made in these losses.

5. The presence of CO with O_2 in the waste gases indicates improper mixing of fuel and air. The excess air was found to be only 20 %, however, so that it would be difficult to improve this loss by unburnt CO without taking the risk of admitting too much air and thus making conditions worse. This loss may, therefore, be accepted as being about the minimum possible under practical working conditions.

6, 7 and 8. These items have been inserted chiefly to prove their comparative unimportance. Attention may be particularly directed to item 6, which is extremely low for practical working. Nothing better could be expected.

The loss by radiation in item 9 is about the minimum amount that could be obtained with a well-lagged boiler and setting, and would be difficult to improve upon.

The general conclusion from this test is that the boiler was working under first-class conditions and gave excellent results, which could be little improved upon.

Metallurgical Furnaces (Sources of Loss).

Consider next a metal-melting furnace for which the " specific thermal efficiency " can be determined.

Take the case of a malleable-iron melting furnace delivering an average of $1\frac{1}{2}$ tons (3360 lb.) of molten iron per hour and fired with pulverised coal. This is essentially a high-temperature operation, the average working temperature in the combustion chamber being in the neighbourhood of 1600° C. (2910° F.).

The actual melting point of malleable iron (which is almost pure iron) is about 1450° C. or 2542° F., varying somewhat according to the carbon content. Its average specific heat up to this melting-point temperature may be taken as 0·1675, and in a liquid state as 0·20. To ensure easy running when molten it would be usual to superheat the metal to about 1530° C. (2786° F.) before pouring. Assuming the temperature of metal charged into the furnace as 19° C. (66° F.), the temperature range of the operation would be $1450 - 19 = 1431°$ C. (2576° F.) at melting point, and a rise of $1530 - 1450 = 80°$ C. (114° F.) from melting point to superheat temperature.

The weight of metal per hour is $1\frac{1}{2}$ tons, or $1{\cdot}5 \times 2240 = 3360$ lb., or $\frac{3360}{2{\cdot}204} =$ 1525 kilos.

Total heat to melting point $= 1525 \times 1431 \times 0{\cdot}1675 = 365{,}620$ Calories.
From melting point to superheat temperature $=$

$$1525 \times 80 \times 0{\cdot}20 = \quad 24{,}400 \quad ,,$$

Total at pouring temperature 390,020 Calories.

Say, 390,000 Calories per hour.

Alternatively in B.Th.U. :—

	B.Th.U.
Total heat to melting point $= 3360 \times 2594 \times 0{\cdot}1675$	1,459,025
From melting point to superheat temperature $= 3360 \times 144 \times 0{\cdot}20$.	96,768
Total B.Th.U. .	1,555,793

Say, 1,555,790 B.Th.U. per hour.

It is assumed that the furnace under consideration is fired with pulverised coal and consumes an average of 625 lb. coal per ton (2240 lb.) of metal melted; or, $625 \times 1{\cdot}5 = 937{\cdot}5$ lb. per hour, $= \frac{937{\cdot}5}{2{\cdot}204} = 425$ kilos per hour.

If we use coal having a composition similar to that given in the case of the billet reheating furnace previously considered, the calorific value of fuel used is 7702 Calories per kilo, or, 13,860 B.Th.U. per lb. The heat supplied to the furnace is then :—

$7702 \times 425 = 3{,}273{,}350$ Calories, or, $13{,}860 \times 937{\cdot}5 = 13{,}000{,}000$ B.Th.U.

The overall thermal efficiency of the furnace will be :—

$$\frac{390{,}000 \text{ Cals.}}{3{,}273{,}350 \text{ Cals.}} = 11{\cdot}9\ \%, \text{ or, } \frac{1{,}555{,}790 \text{ B.Th.U.}}{13{,}000{,}000 \text{ B.Th.U.}} = 11{\cdot}9\ \%.$$

That is to say, 88·1 % of the heat in the fuel supplied to the furnace is wasted. Nevertheless this is a very good result in practice, and compared with other methods of firing a malleable-iron melting furnace shows a considerable saving in fuel.

By calculation in the same manner as previously described, the distribution of heat used and lost will be :—

(1) *Heat usefully employed in heating and melting the metal.*

This has been shown to be equal to 390,000 Calories, or 1,555,790 B.Th.U., or 11·9 % of the heat supplied.

(2) *Heat lost in waste gases.*

The fuel may be assumed to be burnt with 25 % excess air as before when the waste gases from 100 grams of coal have been previously shown to consist of :—

	Mols.	Percentage.
Carbon dioxide (CO_2) . . .	6·365	13·96 %
Water (H_2O) (uncondensed) . .	2·355	5·173%
Sulphur dioxide (SO_2) . . .	0·0325	0·007%
Oxygen (O_2)	1·865	4·1 %
Nitrogen (N_2)	34·9316	76·76 %
	45·5491	100·00 %

The maximum working temperature in the combustion chamber of the furnace under consideration is 1600° C.; it may, therefore, be assumed that the temperature of the waste gases leaving the furnace is at least 1000° C., because the melting hearth of a malleable-iron melting furnace is comparatively short and the waste gas exit is in close proximity to the hearth.

By reference to table at p. 403 the thermal capacity of the waste gases in Calories per molecular volume or mol. at 1000° C. will be determined as follows :—

Carbon dioxide (CO_2) 12·22; water vapour (H_2O) 10·98; nitrogen (N_2) 7·43; oxygen (O_2) 7·43; sulphur dioxide (SO_2) (amount negligible).

The heat in the waste gases is then :—

Carbon dioxide	6·365	×	12·22	=	77·8
Water vapour	2·355	×	10·98	=	25·85
Nitrogen	34·9316	×	7·43	=	259·5
Oxygen	1·865	×	7·43	=	13·85
				Total	377·00 Calories.

The above represents the heat in the products of combustion from 100 grams coal, and the heat in the gases from 1 kilo would be 3770 Calories.

In the furnace under consideration 425 kilos coal per hour are consumed; therefore, there will be :—

3770 × 425 = 1,602,250 Calories in products of combustion from furnace per hour = 49 % of the heat in fuel supplied to furnace, and passing away in the waste gases.

(3) *Lost in ashes and slag.*

In this case the slag and ashes would be run off from the furnace in a molten state at a temperature at least equal to that of the metal 1530° C.

Full data on the specific heat of slags from metallurgical furnaces are not available, but in the absence of strictly accurate information a figure of 0·35 may be assumed for the specific heat of molten iron slag at 1530° C.

The temperature range is 1530 — 19 = 1511° C. The coal under consideration contains 10·58 % of ash, or 425 × 10·58 = 45 kilos of ash slag deposited in furnace per hour.

Then, 45 × 0·35 × 1511 = 23,800 Calories per hour, or, 0·73 % of the amount of heat supplied to the furnace is lost in the metal slag. This is of little consequence.

(4) *Lost by radiation from furnace walls and unaccounted for.*

In this case the balance of the heat remaining after determination of the foregoing distribution must be assumed to be lost by radiation, etc. A heat balance may then be set out as follows :—

Heat usefully applied melting and superheating metal . .	11·9 %
Heat lost in waste gases	49·0 %
Heat lost in slag and ashes	0·73 %
Heat lost by radiation, etc., and unaccounted for . . .	38·37 %

This clearly shows again the great loss of heat that occurs in the waste gases and by radiation. The latter cannot be readily reclaimed, but the former should be recovered in steam raised by means of a waste heat boiler, or for other purposes more suitable for factory requirements.

The lagging of a furnace outside will prevent the radiation of heat necessary to maintain the inner surfaces of refractory brickwork below fluxing or fusing point. The prevention of radiation loss may well introduce heavier expense due to wear and tear of furnace linings and walls, and stoppage for frequent renewals.

CHAPTER VI

COAL WASHING AND COLLOIDAL MIXTURES

Comparison of Coal-washing Methods—The Harris Coal Washer—The Underlying Argument for Wash-Sizing—Froth Flotation System—The Trent System—Mixtures of Oil and Coal known as Colloidal Fuel (Lindon Bates System)—Use of Colloidal Fuel for Locomotive and Marine Purposes—Comparison of Colloidal Fuel and Pulverised Fuel—Experiments on Great Central Railway—Lindon Bates Process (Further Notes)—Application of Colloidal Fuel—Calvert Apparatus.

(Notes on Coal Washing and Washery Plant, by W. A. Harris)

The cleansing of coal from dirt and incombustible matter is a question of great importance to the users of fuel, and in order to show that this operation can be effected by the installation of compact and simple coal-washing plant the notes given in the first part of this chapter dealing with straight water washing have been contributed by W. A. Harris, who has given many years of studied attention to this question, and is the inventor and designer of the Harris Washer described hereafter.

In a discussion following upon the reading of a paper by the author at the Iron and Steel Institute (1919), H. M. Ridge made the following special reference to the effect that inert material has upon the flame temperature of fuel :—

"Heating efficiency curves showed extraordinary results when comparing fuel of different composition, and the flame temperature was rapidly reduced with increasing ash content. As an example he would mention the use of non-combustible dust by the coal miner as a means of preventing the spread of a colliery explosion. Using powdered coal very high in ash was really doing something similar; the ash reduces the temperature, reduces efficiency, and in an extreme case could extinguish the flame; at the same time it added an undesirable impurity which not only affected the composition of the product from the furnace, but which was also going to seriously affect the life of the refractories used. That was an aspect which had to be considered. On the contrary, there were huge coal washeries laid out on an elaborate scale. If powdered coal were to be used, and if the coal were to be supplied to the smelting works as high in ash as was being done to-day, and as had been done during the war, it would necessitate further steps being taken, at enormous expense, because the user would have to separate the ash. Doing that, during combustion in a furnace, was most wasteful."

Coal high in ash, as mined, should be washed free of the greater portion of the ash either at the collieries or on the users' premises. If it is considered impractic-

able to wash coal at the mines in such large quantities as are required by industry, then the users of the coal should certainly instal the relatively inexpensive simple coal-washing plant at their own works. Whether the coal is to be used in the gas producer, on boiler grates, or in metallurgical furnaces, the elimination of the high percentages of ash in coal will contribute to all-round economy in works costs.

Reverting to the opinion of H. M. Ridge, ash-free coal will have a very greatly reduced fluxing action upon the refractory linings of furnaces, and will give higher furnace temperatures. The time taken for heating or melting will, in consequence, be less than when coal containing heavy quantities of inert material (ash) is used, and the time, labour and expense for constant removal of the slag or clinker formed will be saved.

Another point is that by the removal of ash prior to burning the fuel on grates there can be little or no ash dust passing out of a chimney to become a nuisance in the neighbourhood.

Comparison of Coal-washing Methods.

Close consideration, therefore, should be given to washing slack coal, crushed rubbish from picking belts in the screen houses at collieries, wagon or tub road sweepings, and the reclamation of coal from waste dumps by washing.

Generally speaking, it is not necessary to wash sized coal larger than French or Double Nuts because at or above this size ($2\frac{1}{2}$-in. cube) hand picking can be efficiently performed, but with the present, and possibly the future, high cost of labour this limit of size may have to be extended and the larger grade, or "cobbles" (4-in. cube), be washed, so that labour can be economised in the handling and burning of fuel of increased heat value.

It is an axiom that coal breakage at collieries should be avoided to the fullest extent, so that "clean" coal can be delivered to customers in as large pieces as possible. A certain amount of breakage is, however, unavoidable in all operations of coal handling or treatment, starting from the cutting or shot firing, wedging or pick work, at the coal face underground, and continuing until the final utilisation of the fuel at industrial works. Hence the need of careful consideration by coal-handling machinery suppliers, in order to prevent unnecessary or uncalled-for breakage.

The subject of coal washing, broadly stated, embraces the mechanical handling, and the freeing and separating of coal from dirt in bulk, and there are many types of machines or systems in vogue for the purpose.

The initial washing or separating operation is a combined floating, sinking and sifting process, which probably originated on the Continent of Europe, or was, at least, successfully developed in France, Belgium and Germany at a time when in English, Scotch and Welsh collieries the "cream" of the coal seams was, and perhaps is in some cases still, mined and sorted in a very wasteful manner.

"Jig-concentration," of which coal washing is an inversion, is ancient history so far as this is applied to the treatment or dressing of metalliferous ores.

As a consequence, most of the up-to-date and comparatively efficient coal-

washing machinery was, until quite recently, supplied by the more progressive engineering firms of Germany, Belgium and France, but at the present time there are many firms in England, America and other countries that are engaged in the supply of home-produced washing plant, either of original design, or based upon the earlier foreign types with improvements that have been introduced.

The detailed items of feeding, and of crushing and screening machinery (either arranged to operate before, during or after the washing operation), also the subsequent distribution, collection, or drainage of the washed products, are largely questions of individual preference, and are to an appreciable extent controlled by site conditions. It is not proposed therefore to particularise these purely coal-handling equipments, but to confine these notes to the actual coal-washing plant, and the theory or practice of coal and dirt separation. The requirements necessary are sufficient floor space and adequate quantity of coal to be treated within reasonable distance of the projected installation. In all cases the actual layout of plant must be planned in accordance with the conditions of raw coal supply, the rate at which fuel is to be graded or washed, and the subsequent utilisation, if possible, of the waste products from the washing plant.

When it so happens that there is a large percentage of " duff " or " fines " in the raw coal, the necessary plant area must be increased to provide for " settling-out " tanks or troughs from which the fine coal can be recovered by special collecting machinery. This extra area of works and cost of collecting plant are, however, compensated for by the lower power required for the actual washing operation as compared with the washing of " peas " and " nuts " coal.

For washing 100 tons per hour of coarse slack coal having average proportions of " nuts," " peas " and " duff," and allowing for the preliminary breaking down of lumps to the " nut " size, for intermediate roll crushing and rewashing of " mixed " coal, also taking into account the power used in screen sizing either before or after washing, a fair average power allowance would be 100 b.h.p., or 1 b.h.p. per ton per hour of coal treated. Such plants might be operated at about 80 b.h.p., but 1 b.h.p. per ton would be a safer figure to adopt for general practice with a medium-sized plant, and for efficient separation of the free dirt from the coal.

Correct water-conveying methods, and time of settlement, are important as tending towards success or failure in coal-washing plants, but the proper design and operation of a coal-washing machine or machines is the crux of the whole question, and unless the coal and shale (or dirt) are efficiently separated whilst passing through the coal-washing machine, no amount of care expended on the subsequent plant, whether upon its arrangement or operation, will give the desired result.

The degree to which separation takes place should mean both clean coal and clean shale, *i.e.* clean free graded coal at coal outlets, and clean free shale at shale outlets.

It is always possible, and may even be advisable, to arrange for a small percentage of shale to be discharged with the washed coal, so as to make certain that no coal is carried over and lost with the dirt. On the other hand, if coal is to be washed to the maximum possible limits, a small percentage of coal must be discharged with the shale so as to effect the discharge at washed-coal outlets of coal commercially free from shale or dirt.

The efficiency of any coal-washing plant should be such that not more than 1% of free shale should remain in the washed coal, and not more than 1% of coal in the shale.

There are, however, many inferior coals which are so intergrown or laminated with shale in quite small pieces that unless these are crushed to "duff," and the coal almost entirely freed, it is not possible closely to guarantee results. In these cases small composite pieces containing perhaps two parts shale and one part coal would probably reach the shale outlets, whilst, conversely, pieces made up of, say, two parts coal and one part shale would be floated off with the washed coal. It will readily be seen that under these conditions the results given at the washed-product outlets will depend to a great extent upon the proportions of such pieces that are fed into the plant with the unwashed coal.

In other cases certain grades of coal are accompanied by highly carbonaceous "bone" or "band" materials which would appear at both the shale and the washed-coal outlets in quantities according to the nature and prevalence of these substances. The only satisfactory way to eliminate foreign material of this kind is to introduce an intermediate roll-crushing process, and then to rewash the product. In the absence of any definite line of demarcation between carbonaceous matter and shale, an arbitrary clean-coal line can be based upon a specific gravity for usable coal of, say, 1·75 or even 2·00.

Many slack coals occur in close alliance with finely divided fireclay and other earths, which will float off with the "duff" coal. In such cases special treatment must be resorted to if efficient removal of coarse dirt in addition to finely divided earthy material is to be effected.

The term "classification," as used in the grading of minerals, is misleading when applied to screens in coal-washing plants. This term belongs essentially to metalliferous ore treatment, and in these notes dry or raw coal screens will be referred to as "sizers," or as "water drainers" if applied in this manner.

Coal-washing machines or systems may be appropriately divided into three classes: Fine Coal Equipment, Sized Coal Equipment, and Unsized Coal Equipment, according in each case to the range of application.

It is common knowledge that dust coal, small clean coke, cinders, etc., will remain in suspension or float on water, or that they will sink very slowly in a gently flowing stream of water. In practice it will be found that clean coal, cinders and even coke when thoroughly wet will be carried below the surface of the water, and will accumulate there because of superimposed dirt. Some means of stirring or agitation is, in consequence, necessary to keep the mass in motion, and to allow the flow of water to carry the lighter or smaller materials towards the overflow.

The most obvious and simplest method for effecting this separation is to place the water-supply inlet below the working water level. The tendency for the water to follow the path or paths of least resistance introduces a difficulty due to what is known as "pocketting," with consequent loss of coal at the shale outlets. This difficulty is partially countered when the water enters at the side of the apparatus, and when screens and other obstructions are provided against which the incoming water can impinge and so become fairly well distributed. Water may also be made

to enter at the bottom of the apparatus, and screens, broken slate, etc., are placed at an intermediate depth with the object of splitting up the water streams. By imparting a vortex, swirling action, or lateral wave movement to the upward-rising water the tendency to " pocket " can be practically eliminated. All these methods are not only wasteful but at best not particularly efficient, and necessitate the use of a continuous supply of water. By careful sizing through screens it is possible to provide a suitable bed depth of the particular coal particles under treatment in each compartment, which has nearly equal resistance to the rising water, and this is a method sometimes employed. A complete unit of this description, comprising screens, pump and washing apparatus, makes a somewhat cumbersome and expensive plant in relation to capacity obtained.

Another method adopted extensively with good results is to provide for a minimum supply of water in conjunction with a plunging or moving bed. By this means a jigging, or intermittent pulsating motion is imparted to the water and also to the coal. Thereby the coal bed is alternatively opened to, and sealed against, the upward flow of water and to the passage of shale or dirt travelling downward. Air pressure on the surface of the water in an adjoining, communicating, chamber, is made use of in some washing machines to effect this pulsating action.

Whilst dealing with fine coal washing (slurry and grain) the froth flotation system (see p. 108) should be mentioned. In this process, the affinity between bright surfaces of coal and the agitated oil scum is made use of because there is an increase of surface tension between the coal particles and the oil scum as compared with the surface tension between coal particles and water. The straight sizing and washing of coal cannot be accomplished by this method, but it is of importance when dealing with very fine fuel, and when it is necessary to wash coal dust carrying fire clay, etc.

There are several well known and accepted methods of washing slack coal, closely approaching one another in efficiency of washing and power consumption based on input or output.

In the more usual type, nut, pea, and duff coal is fed in bulk either to a single machine or to a series of similar machines, in which the large shale is extracted, and the washed nuts and peas are subsequently separated by means of wet sizing screens, after which the " throughs " from these screens are water conveyed to other machines for re-treatment.

With soft friable coal it may be argued that screening after washing is preferable, in order to reduce the risk of making " smalls," and it should then be borne in mind that water conveying to screens, and wet sizing in slowly moving screens, can be employed with success. In this manner the washed coal only is screened, and the sizes leave the screens ready for the market.

An old but still common fault in design of coal-washing plants has been to provide a common shale outlet for several compartments of the same washing machine. This necessitates connecting apertures or passages between the compartments below the coal and water levels, and as a result water is repeatedly forced to and fro by the pulsations without achieving any useful purpose.

In all coal-washing machines, the washed coal overflows at surface outlets and dirt or shale is extracted from bottom outlets.

The Harris Coal Washer.

Fig. 8 illustrates a commercial size of water agitation coal-washing machine designed for treating dirty and dusty coal containing mixed peas and duff. The water pulsations are introduced through plunger control valves, and the water supply is obtained from a single stage centrifugal circulating pump. The raw coal feed is introduced at one end of the machine, and the washed coal overflows at a side outlet near the other end. The shale from the duff coal sinks through a series of perforated bed screens and is extracted at three bottom outlets, each controlled by a check valve. The shale from the pea coal is carried through and out of the machine by a drag link conveyor.

Actual tests run with average coal containing 40% of inert material (total free and fixed ash) show that approximately 30% of the raw feed or 75% of the total percentage of ash is extracted. Of this quantity of dirt, the shale conveyor deals with two-thirds, and the balance is drawn off through the dirt outlets at the bottom of the washer. The fixed ash in the coal goes 8%.

It will be seen, in this type of washer, that the coal, the shale conveyor, and the water are all moving in one and the same direction, viz., longitudinally from end to end of the machine.

The sizing of coal should not necessarily be done prior to washing, for dry sizing screens are notoriously inefficient, wasteful of power, and expensive both in first cost and for repairs. It is much better to adopt machinery which will efficiently carry out sizing and washing as a simultaneous operation.

The simplest, most efficient and economical method of washing small coal, as found by Harris in practice, is by intermittent water pulsation obtained direct from suitably arranged valves and circulating pumps. In coal-washing plants built on this principle the finest coal, or mixtures also containing grains, peas and nuts, can be completely washed and sized. With such a machine it is unnecessary to subdivide the sizes by means of screens prior to washing. Fine dirt down to 200 mesh is readily extracted in washers of this type.

The Underlying Argument for Wash-Sizing.

If a mixture of nut, pea and duff coal (unwashed) is fed to a washing-machine, or one compartment of it, fully charged with water, and jig-pulsated for a few seconds, it will be seen, on draining off the water, that the finest slurry coal has settled on top of the remainder, and that the top of the coal bed is level. On cutting into this bed of drained coal it will be found that as one goes deeper one uncovers larger and still larger coal, also that the large shale has accumulated at or near the level of the bed screen. During the jigging operation, if a testing rod is placed vertically upon the coal bed, it will be seen that the rod will sink slightly at each pulsation until it rests on the screen supporting the bed of coal.

With a suitable depth of bed and intermittent water agitation in the washer the pulsating effect is not quite so clearly defined as in a plunger jigging machine. This is on account of the slightly different action of the "rise" and "rest" periods with the jig-pulsation method. A test rod inserted vertically into a solely water-

agitated mixture will sink immediately to the bed level, for it will not be held up by the coal bed between the pulsations, as in the jig-washer.

Harris states that he has closely followed results obtained in practice with both systems, and from actual experience definitely advocates washers operated on the water-agitation principle. Machines of the latter design are quicker than plunger or jig-frame washers, and for equal capacity require less space. The lifting effect given to a coal bed by water agitation is dependent on the resistance of the materials to the passage of the water. The resistance is to a great extent of the nature of surface friction, especially with peas and larger sizes of coal. When duff and small granular pieces are present, the interstices between the larger pieces of coal are filled up, and the resistance of the bed to the passage of rising water is increased in consequence, thus permitting a much shallower bed of mixed sizes to be lifted than would be possible when larger size coal alone is under treatment.

It is found that, owing to the variability of this coal-bed resistance, a sharp upward water pulsation must be given if the materials are to be effectively released and the coal lifted from under the incoming feed, also to float off the washed coal at the outlet.

When coal washing and separation are accomplished by means of the plunger system there is always a pull back or fall of water level between the pulsations, and this also occurs to a somewhat lesser degree when the air-pulsation system is employed. This pull back has the effect of sealing the bed and tends to prevent the small dirt from sinking through to the screen.

Intermittent water agitation in combination with plungers greatly reduces the effect of " pull back," and used alone entirely removes this defect when duff and peas coal are treated.

By utilising low-pressure water pulsations, the bed never becomes fully sealed, and the coal is therefore kept in a state of semi-flotation. The bed screen apertures and the interstices between the pieces of large shale covering the screen are always open for the downward passage of fine dirt.

In practice there will also be found a zone between the screen level accumulations and the water or semi-flotation level where small shale and " mixed " coal (part coal and part shale) will accumulate. The smaller grades of material at this level, whilst allowing the down passage of small dirt, will effectually prevent the sinking or loss of small clean coal.

Fig. 10 is a diagrammatic representation of one form of such a machine in which A is the top or return strand of a drag link conveyor in the machine, partly immersed in the water and coal. B is the bottom, or forward, strand of the same conveyor, wholly submerged in the agitated mixture of water, coal and mixed coal (pieces of coal with shale adhering thereto). D is the feed compartment for the raw coal, and this acts both as a wetting compartment and as additional area for the washing of small coal. C is the washing compartment for small coal, E that for peas, and F for nuts coal. X1 and X2 are the bottom outlets for " brasses " and the finest grades of dirt. X3 and X4 are the bottom outlets for the next grades of fine dirt. G is an outlet fitted with hand-controlled valve for the discharge of larger shale. H is the outlet for intermediate shale and mixed coal, carried out on the lower

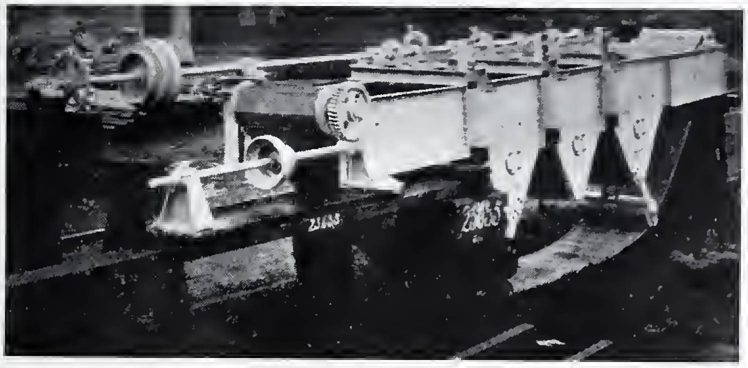


Fig. 8.—Harris Coal-washing and Sizing Machine.

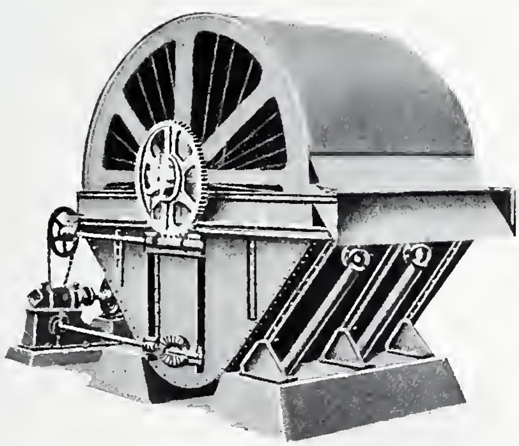


Fig. 9.—Oliver Rotary Filter.
Oliver Continuous Filter Co.]

[*To face p.* 106.

strand B of the moving dirt conveyor. J is the end overflow outlet for small washed coal, while K, L and M are side and end outlets respectively for washed "pea," single-nut and double-nut coal. The machine operates and functions in the following simple manner :—

Let it be assumed that the machine is full of coal and that it is to be started up from rest. The water pulsations from the circulating pump are first started up and the machine is filled with water. Raw coal is then fed to compartment D and the conveyor clutch put in. The conveyor strand A will then travel with the flow of water in the direction of the arrow, and it will spread the coal feed in such manner that the small coal will be moved towards its washed outlet J. Meanwhile the bulk of the coal feed will be in course of stratification. The large pieces of shale will sink down on to the bed screen, and spreading thereon are in course of time dis-

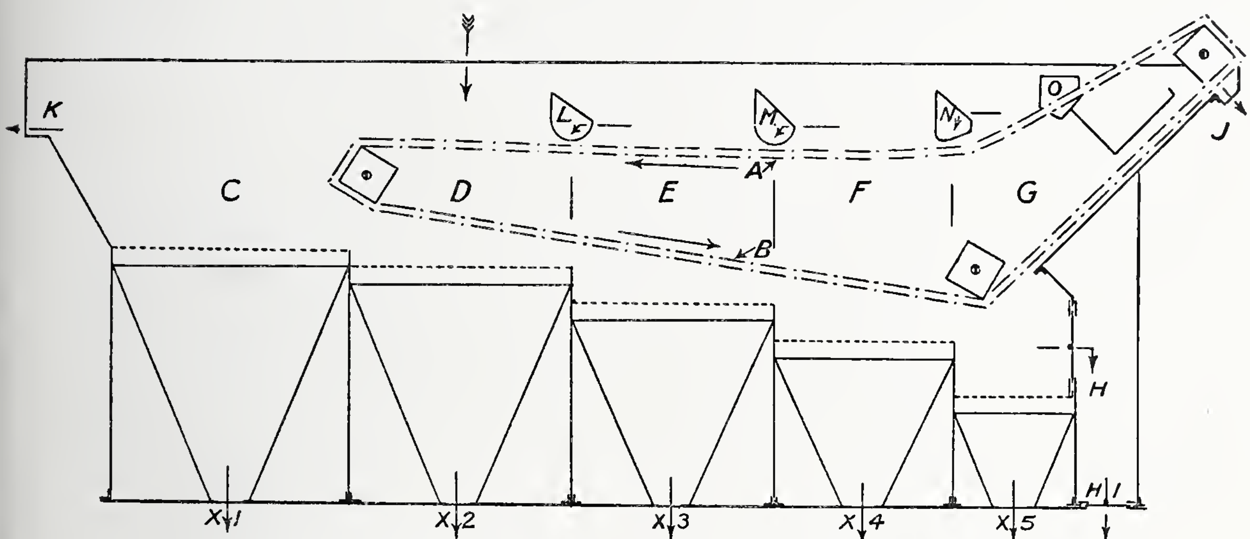


Fig. 10.—Diagram of Harris Coal-Washing and Sizing Machine.

charged at the outlet G. The nut and pea coal, together with the intermediate shale, are moved in the same direction as the large shale by the conveyor strand B. On reaching the compartment E, which is of smaller area and deeper than compartments C and D, the coal and dirt mixture is subjected to slower and stronger water pulsations. The peas coal is lifted to the water surface, where it meets strand A of the conveyor moving in the opposite direction to strand B, and, assisted by the water flow, is carried towards the peas coal outlet K.

The remaining coal and dirt are then carried to the compartment F, which is of even smaller area, and of greater depth than compartments C, D or E, and therein the water pulsations are yet slower and stronger. The small nut coal is lifted to the surface and impelled by the flow of water to the outlet L.

Due to the pull of the lower conveyor strand B on one half of this compartment F, the large or double nut coal will heap up at the end nearest to the large shale and mixed coal outlets, and is extracted at the outlet M.

From time to time one sees references to methods for washing coal in a fluid or

fluids heavier than water. Such a system has been recently patented in Germany, and is said to give good results. Prof. Henry Louis of Newcastle-on-Tyne tentatively advocated a similar method some fifteen years since, and for large coal a heavy fluid would be an undoubted advantage, for it would automatically assist the clean coal to float.

For this purpose a simple washer operating upon the intermittent fluid pulsation principle should meet all requirements, excepting when very dusty and dirty coal is to be treated.

With further reference to the presence, in raw coal, of light materials such as fireclay or fuller's earth, there are three methods of separating these materials from the washed products, viz. :—

(1) Fine screening, wet or dry, (2) filtration and (3) settlement and decantation.

In each case, for the successful elimination of such materials from the duff coal, it becomes necessary to arrange for the loss of a proportion of the finest or slurry coal.

Froth Flotation System.

The well-known Froth Flotation process of separating small coal from superfluous ash has been widely developed by the Minerals Separation Co., Ltd., in Great Britain and elsewhere. The process is essentially one for separating coal from "dirt," and departs from the ordinary water-washing methods in so far that separation is not dependent upon the difference between the specific gravity of the coal and that of the dirt. It is a "flotation"[1] process closely embracing the methods which have been adopted with such success in the concentration of minerals from low-grade metallic ores, and is supplemental to the gravity coal cleaning or classification systems.

The coal to be cleaned is first ground to a powder so that the particles will pass through a $\frac{1}{10}$ in. aperture screen, and the material is then mixed with from four to six times its weight of water. This mixture is then violently agitated by any suitable means, during which operation a small quantity of reagent is added. The reagent used is an oil, the quantity used being so small, about 1 lb. per ton of material treated, that it is not recovered.

During the period of agitation in conjunction with the reagent there are produced a multitude of minute air bubbles which attach themselves only to the coal particles, which thus become buoyant, rise to the surface, and are removable in the form of scum or froth. The ash, forming dirt, sinks to the bottom of the vats in which the operation takes place, and is discharged through bottom slurry outlets. The coal carried off in the froth can then be passed through a filter for drying the recovered coal prior to further treatment, such as the making of coke or briquettes, or for use as pulverised fuel after passing through grinding mills to further reduce the fuel particles to the required degree of fineness for application in this manner.

[1] *Froth Flotation : Its Commercial Application, etc.*, by W. Broadridge, The Institute of Mining and Metallurgy, 1919–1920.

Air bubbles do not become so attached to the particles of clay or dirt in the coal, and the inert matter remains as a sediment in the frothing box. The froth containing the combustible matter and an equal amount of water is skimmed off the surface and passed through to a filter, such as the Oliver filter, Fig. 9, in which type of machine approximately one ton of filtered coal will be recovered per sq. ft. of filter surface per twenty-four hours, the moisture content remaining in the filtered fuel being about 12 to 15%.

Recovery of coal by this process is high, and, with efficient plant and suitable coal waste, 90 to 95% recovery can be made in practice, and ash reduced from 70% down to 10 or 15%.

It was also found that not only was a richer gas obtained, but also an increased yield of by-products when the cleaned coal was charged into the coking ovens.

So far as the washing of coal for subsequent use as pulverised fuel is concerned, it is an open question whether these special processes, Froth flotation or the Trent process, referred to later, offer greater advantages than the straight washing and grading of coal in ordinary water washers such as the Harris washer already described.

For the Froth flotation process the material is usually ground to about $\frac{1}{10}$ in. size for the recovery of the combustible material and to approximately $\frac{1}{200}$ in. size if subsequently used as pulverised coal. In the Trent process the required degree of fineness as a pulverised fuel is apparently obtainable in the one operation.

Inferior grades of coal can be rough crushed, washed in water, and sized if necessary without the use of oil as a reagent. Moreover, the subsequent grinding of mixed sized lumps, small coal and dust, is a better proposition than the grinding of say all $\frac{1}{10}$-in. particles and dust in a mill, for with all "fines" there is a tendency for this material to paek and stifle the grinding elements. The presence of coarse or lump coal greatly facilitates the operation of fine pulverisation.

The figures given in the following table represent the grading of the product obtained by the Froth flotation process, and the continuous rotary filter, the original analysis of the coal showing 14% ash. It will be seen that in the recovered coal there is but 3·5% ash.

SCREEN ANALYSIS OF COAL CONCENTRATES FROM THE OLIVER FILTER, SKINNINGROVE, YORKSHIRE, ENGLAND.

Over.	Under.	Weight %.		Ash %.	
		Direct.	Cumulative.	Direct.	Cumulative.
20 mesh.	10 mesh.	58·6	58·6	2·7	2·7
40 ,,	20 ,,	8·3	66·9	3·2	2·76
60 ,,	40 ,,	5·3	72·2	4·0	2·85
100 ,,	60 ,,	5·3	77·5	4·5	2·96
150 ,,	100 ,,	5·3	80·0	4·8	3·03
200 ,,	150 ,,	2·6	83·4	5·4	3·11
—	200 ,,	14·0	97·4	5·9	3·51

At these works at which coke is produced from coal recovered by this method, the reduction of ash to about 4% means that the capacity of the coking ovens is increased by approximately 10%, and the actual quality of the coke produced is very appreciably improved.

In the making of colloidal mixtures the resultant quantity of oil remaining in the recovered coal is an advantage, and not an unnecessary expense, which conceivably it might be when the fuel is to be burned in pulverised form, or as briquettes.

On the other hand, in certain circumstances it will be seen that the presence of a small quantity of oil is beneficial in pulverised coal (see " Atritor " machine) when it becomes a question of burning unwashed low-grade high ash coal containing but a small percentage of volatile matter.

In addition to its use in conjunction with the Froth flotation vats, the Oliver filter should prove very serviceable in the drying of combustible matter recovered from waste coal by ordinary water washing. The rotary Oliver filter, as shown in detail in Fig. 11, is extensively used in the recovery of metalliferous slimes in mining processes. The solution is contained in the lower section, the exposed portion of filter drum becoming immersed in the solution as it revolves.

The drum is made in box section with double wall formation, so that a vacuum can be produced in each section as it is leaving the solution, thereby freeing the water by suction through the filter cloth or gauge, and leaving the dried cake adhering to the periphery of the drum, to be scraped off by the scraper shown in the illustration.

The use of such filtering machines in place of the large settling tanks into which washery slurry is run at many collieries would no doubt be advantageous in expeditiously recovering the fine fuel, and an installation of rotary filters could be used with advantage in any process of manufacturing briquettes from washed colliery waste coal.

The author has on every possible occasion advocated the recovery of waste coal from colliery dumps, and has pointed out that this might be considered such a profitable development of scientific reclamation of saleable coal that capital on a large scale could be usefully employed in an industry of the kind. In this connection it will be of interest to quote some of the remarks made at the Annual General Meeting of Minerals Separation, Ltd., 1920, by the Chairman, F. L. Gibbs (*The Financial Times*, November 25th, 1920).

The Chairman, after referring to the great activity of his company on coal-recovery projects, and to the various large contracts and important agreements entered into with colliery owners in Great Britain, France, Spain, and China, with proposals for Brazil, South Africa, India, Japan and elsewhere, said :—

" The quantity of material under option to us is very large, and we anticipate that this enterprise will eventually become a very important one.

" We are also engaged in the examination of many large waste heaps in various parts of the country, and some of these show promise of a large business on sound commercial lines being developed. The waste coal heaps over which we have

acquired options amount to several millions of tons, and negotiations are now being conducted for further quantities of this material. Systematic and thorough sampling of the heaps is essential in every case, and our engineers are already engaged upon this important work. We anticipate that it will not be long now before we shall be in a position to form an estimate of the commercial value of what we have under examination, and although, of course, we must expect that some of

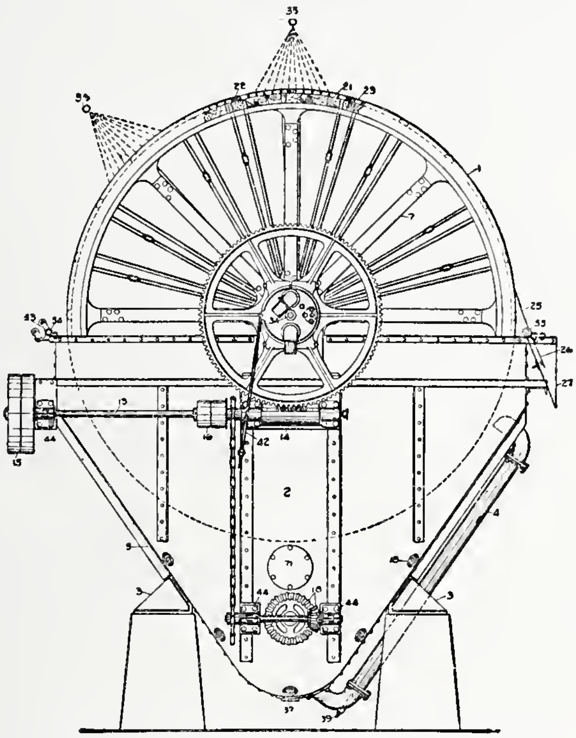


Fig. 11.—Detail View of Oliver Filter.

(The Oliver Continuous Filter Co.).

1. Filter Drum.
2. Filter Tank.
3. Tank Feet.
4. Air Lift Circulators.
5. Tank Manhole.
6. Channel Steel Drum Rim.
7. Channel Steel Drum Arms.
8. Hollow Cast Iron Trunnion.
9. Steel Drum Shaft.
10. Main Bearings.
11. Agitator Stuffing Boxes.
12. Worm Drive Gear.
13. Worm Shaft.
14. Oil Well for Worm.
15. Filter Drive Pulley.
16. Wiring Pulleys.
17. Chain for Agitator Drive.
18. Bevel Gears.
19. Agitator Shaft.

19*a*. Agitator Stub Shafts.

20. Agitator Shaft Bearing.
21. Wood Staves—Drum Shell.
22. Division Strips.
23. Filter Medium.

this raw material will not contain sufficient coal to treat profitably, we have good reason to suppose that many of these heaps will prove to be very profitable.

"I cannot, I think, more strongly emphasise the potentialities of our coal business than by quoting here the written opinion of two of the most eminent authorities on the coal, iron and steel industry, namely, Mr. Hutchinson, managing director, and Mr. Ernest Bury, director and formerly general works manager, of the Skinningrove Iron Co. :—

" 'The extraordinary flexibility of the flotation method of washing coal, which permits the treatment of all grades of fuel down to the smallest dust, in our opinion, will become an asset of national importance. There is no pit heap containing coal, or washery heap, or fine dust, or other colliery waste, from which the coal cannot be completely recovered by this method of treatment. It may prove that valuable business can be established in the purchase of waste heaps, which colliery firms have hitherto neglected. The adoption of this process will render available for use in the iron and steel industries, and other consumers of coal, large quantities of fuel which have hitherto been regarded as valueless, or even, in some cases, been thrown to waste.' "

The Trent System.

The Froth Flotation process has been briefly described. In the author's opinion the Trent system offers many additional advantages in connection with the reclamation of coal from the accumulation of mine waste, and especially so when the recovered coal is to be used as a colloidal fuel.

The following description of the Trent system has been taken from *Power*, August 2nd, 1921, in which a review of notes and papers on this subject by O. P. Hood, G. St. Perrott and S. P. Kinney, of the United States Bureau of Mines, is given.

The use of oil in cleaning coal as applied in the Trent process embodies the application of the principle of differential wetting of coal and dirt by oil or water.

During the war certain suggestions concerning power production were made by Walter E. Trent to the U.S. War Inventions Board, and experiments were carried out for removing ash from powdered coal, resulting in the Trent process.

Briefly, the process consists in agitating together powdered coal, water and oil. This produces a partly de-ashed plastic fuel, called an "amalgam," the oil selecting the coal particles and largely excluding the water and ash. The amalgam can be subsequently freed from water by working or kneading the mass in much the same manner as butter is worked.

This amalgam can be burned in several ways: for example, it may be shovelled or forced through pipes by pressure; it can also be stored under water if desired, and is in the very form required for mixing with oil.

In the Trent process the raw material is wet ground to the degree of fineness equal to that stipulated for fuel to be fired as pulverised coal.

Wet grinding not only eliminates all necessity for expensive and bulky rotary coal-drying plant, but at the same time eliminates all possibility of danger from explosion or firing of dry powdered coal during this operation.

For this purpose special grinding machines have been constructed for use with the Trent system. These consist of rotary cylinders containing a number of longitudinal pipes into which are placed loose rods or round bars.

The coal slurry is passed through these tubes and the particles of coal and dirt are reduced to extremely fine dimensions by the grinding action between the rods and the interior surface of the pipes. The coal can either be wet ground in oil or water. In the former case the fine slurry is then mixed with water or in the

latter case oil is added respectively to effect the required separation of the ash from the coal.

If an oil is used that can be distilled at a temperature below the distilling temperature of the coal, dry powdered fuel in suitable form for use as such is reclaimed from the amalgam and the oil may be re-used. If a heavy oil be used and distilled to dryness, a coke product may be recovered, although the coal may have had no coking quality. If the distillation proceed only to a heavy pitch, a mass suitable for briquetting may be made.

In distilling oil mixed with a finely powdered material the distillates are similar to those obtained by distilling under pressure, so that the distillation of an amalgam of coal and oil gives quantities often more favourable than the sum of the separate distillations of the coal and the oil.

When a mixture of pulverised coal and water is agitated with oil in an amount equal to 30 % of the weight of the coal, a clean separation of a considerable part of the mineral matter is obtained. The carbonaceous material forms with the oil a pasty mass that is heavier than water, while the mineral matter that was physically separated from the carbonaceous material by the fine pulverisation remains suspended and can be drawn off with the water.

The mineral matter in coal is classified (1) according to its physical state of subdivision as " intrinsic " and " extraneous," and (2) according to its chemical composition as shale, clay, " slate," and calcite and pyrite. Intrinsic impurities are those that are present in a very fine state of dissemination throughout the coal substances and are not separated from the coal substances even by very fine pulverisation. Extraneous impurities occur in the form of partings, veins and nodules or may be impurities mechanically mixed with the coal during the process of mining. Part of this extraneous mineral matter is removed by the standard methods of washing coal, the amount removed depending on the fineness of crushing necessary to ensure physical separation of mineral matter from coal substance, and on the size of crushed coal that the washery can efficiently treat.

The theory of the Trent process is briefly as follows : Coal particles are more easily wetted by oil than by water. Moreover, the particles of coal are more easily wetted by the oil than are the particles of refuse. The result is that when oil is stirred into a mixture of powdered coal waste and water, the particles of coal are gradually separated from the water, and form with the oil a pasty mass containing only a small amount of refuse. If this pasty mass is then removed from the mixture and separated from its oil, there is obtained a powdered coal containing a low percentage of refuse. Naturally, the method will give best results only where the combination of coal refuse and oil is such that the oil has a much greater " attraction " for the coal than for the refuse.

Tests made with a number of typical coals of the United States gave an ash reduction varying from 30 to 75 %. Sulphur reduction was fairly good in the case of anthracites, but low in the case of bituminous coals. Combustible recovery was, with a few exceptions, better than 95 %. Results point to the desirability of preliminary water concentration of high-sulphur coals for removal of pyrites before treatment by the Trent process. Practically any oil of viscosity not greater

than 135 sec. on the Saybold viscosimeter at a temperature of 25° C. will give satisfactory results in this process. Oils of much higher viscosity may be used under certain conditions.

In most of the work the amount of oil required was about 0·3 lb. per lb. of dry-cleaned coal. In the case of a coal containing 25 % of removable refuse, it would be necessary to use 450 lb., or about 62 gallons, of a light fuel oil per ton (2000 lb.) of raw coal treated. The results obtained point to the conclusion that oil losses in the first stage of the process—that is, agitation and separation of refuse—will be negligible. The amount of moisture in this mixture may range anywhere up to 30% or 40%, although it is usually considerably less.

In the case of raw lignite it has not been found possible to get good separation of carbonaceous material from mineral matter, for the reason that lignites are very readily wetted by water. Once the lignite is well wetted with water, either by wet grinding or by soaking, the moisture is not readily displaced by oil. On agitation of a wet-ground mixture of lignite with oil, there is some tendency for separation into layers of coal-oil and refuse-water, but no formation of compact agglomerate or " amalgam " of coal and oil, which takes place with bituminous coals or anthracite.

There is no restriction as to the grade of coal that can be treated by the Trent process. Fuel containing from 15 % to 65 % ash has been treated. The power necessary to run a 15-ton-per-hour complete plant on bituminous coal is about 130 h.p., or, say, 8 to 10 h.p. per ton of amalgam produced, and for a larger capacity plant 25 to 30 tons per hour less power per ton of output will be required; for this latter duty say 6 to 7 h.p. per ton of amalgam.

The power required when operating on anthracite will be increased by about 50 % and for city ashes about double the power for bituminous coal.

For a 15-ton-per-hour plant roughly fifteen men would be employed, and the number of men would not have to be increased for the larger plant.

When preparing amalgam in this manner, from which illuminating or power gas is to be subsequently made, it is claimed that there is a considerable saving over ordinary methods of making gas from coal. For the making of gas a rich amalgam is advocated, and the B.Th.U. value of 1 lb. of Trent amalgam when $\frac{2}{3}$ lb. of bituminous coal of 14,200 B.Th.U. has been incorporated with $\frac{1}{3}$ lb. of fuel oil of 19,000 B.Th.U. will be 15,800 B.Th.U.

The breaking down of this amalgam and the introduction of additional fuel oil for the purpose of making a sufficiently liquid colloidal oil would be an easy operation requiring but little power to run the necessary mixing vats. For the production of a 60 % oil 40 % coal colloidal fuel, it is claimed that the total power per ton (2240 lb.) should not exceed the 10 h.p. for the 15-ton-per-hour plant and the 7 h.p. figure for the 30-ton-per-hour plant. On this basis, and using the coal and oil referred to above, 1 ton (2240 lb.) of 60–40 colloidal oil would contain about 38,000,000 B.Th.U., or the expenditure of power for production of a relatively ash-free semi-liquid fuel of roughly $\frac{1}{3}$ h.p. per 1,000,000 B.Th.U. value in the colloidal fuel mixture made in the smaller capacity plant, and about $\frac{1}{4}$ h.p. in the plant of 30 tons per hour capacity.

Qualities of Fuel Treated and Summary of Trent Process Results.

Kind of Coal.	Amount Oil used (Gallons) per Ton.[1]	Raw Coal (percentages).			Composition of Cleaned (percentages).			Coal. Total Weight tons.[2]	Refuse (percentages).			Final Results.			Time of Agitation. (hours).
		Ash.	Ash. (corrected).	Sulphur.	Total Weight.	Ash.	Sulphur.		Ash.	Ash. (corrected).	Sulphur.	Ash Reduction (%).	Combustible Recovery (%).	Sulphur in Combustible Reduction (%).	
Anthracite :															
Culm I	65	27·7	30·4	1·00	74·0	7·0	0·70	26·0	87·0	95·0	1·99	74·7	97·8	30	0·5
Culm II	65	31·4	34·8	1·63	69·0	6·5	0·85	31·0	87·0	95·6	3·05	79·2	98·0	48	0·5
Rhode Island . . .	75	21·7	23·8	0·85	82·0	6·7	0·83	18·0	90·7	98·3	0·95	69·2	99·5	—	2·0
Bituminous :															
Pittsburg	80	12·5	14·2	1·27	92·0	6·0	1·34	8·0	88·0	95·2	0·40	52·0	99·5	—	0·1
Upper Freeport . .	80	9·3	11·2	2·28	96·5	6·7	2·34	3·5	87·6	94·8	0·60	28·0	99·7	—	2·0
Bone coal refuse . .	80	21·7	23·9	0·93	88·0	12·5	0·80	12·0	88·7	96·9	2·08	42·3	99·4	14	1·0
Illinois	80	16·6	20·7	5·33	85·0	7·4	5·28	35·0	69·7	76·6	2·25	55·4	89·8	1	3·0
Indiana	80	9·9	13·0	4·38	96·4	6·3	4·27	3·6	86·2	93·5	0·80	36·4	99·8	3	0·5
Oklahoma	80	19·5	23·6	4·74	69·0	5·7	3·08	31·0	50·5	59·0	8·50	70·8	83·5	35	2·0
Washington . . .	80	22·6	24·7	0·49	87·5	13·6	0·50	12·5	85·0	92·1	0·50	39·8	98·7	—	0·5
Bituminous refuse :															
New Mexico . . .	60	54·7	59·3	0·55	45·0	22·9	0·86	55·0	80·6	87·3	0·29	58·1	82·8	—	2·0
Tennessee	50	63·5	69·4	1·64	31·0	20·6	1·48	69·0	82·7	90·2	1·65	67·7	77·8	10	2·0
Alabama	80	23·5	26·2	1·60	80·5	6·6	1·76	19·5	92·8	100·7	0·90	72·0	100·0	—	1·0
Sub-Bituminous :															
Washington . . .	80	19·3	21·1	0·48	87·0	10·0	0·50	13·0	80·0	86·7	0·45	48·4	97·8	—	3·0
Lignite :															
California (carbonised at 500° C.) . . .	80	35·1	39·3	1·77	81·5	25·7	1·56	18·5	75·9	83·2	2·30	26·8	95·0	12	2·0
Texas (carbonised at 500° C.)	80	33·5	36·9	1·44	79·7	18·1	1·42	20·3	94·2	102·4	1·25	46·0	100·0	1	2·0
Bituminous :															
Brazil	60	35·6	39·7	2·47	66·0	9·4	2·32	34·0	86·0	94·4	2·71	73·6	97·0	6	4·0

[1] 1 U.S.A. Gallon = 0·8 Imperial Gallon. [2] U.S.A. Short Ton = 2000 lb.

Mixtures of Oil and Coal known as Colloidal Fuel (Lindon Bates System).

The oil-coal mixtures which are known to-day as "colloidal fuel" may be roughly classed under two headings :—

(*a*) Mixtures more or less stabilised by chemical combination of the solid and liquid.

(*b*) Mixtures of solids and liquids effected by purely mechanical means.

For either of these the dry or wet grinding process can be used, but the latter, constituting the mechanical wet grinding of solid fuel in oil or water, so that a smooth paste is formed in conjunction with the water or oil, is preferable. The elimination of the water from the amalgam and the addition of the required quantity of liquid fuel are subsequent operations, *vide* Trent process.

If during the breaking-down process a special chemical fixature or fixative is introduced, it is claimed by Lindon Bates that there results a more or less total absorption of the solid fuel by the oil, and that there will be subsequently little or no sedimentation or settling out of solid particles.

Bates introduced his process in 1918, and although his colloidal mixtures did not then suggest the entire absence of subsequent sedimentation, it is understood that improvement in this respect has been introduced since that year.

Early attempts made for producing satisfactory colloidal mixtures were briefly referred to by Bates in the following passage :—

" The idea of making a liquid fuel of coal in oil is not new. Herbert Smith and Harvey Munsell in 1879 described a mechanical mixture which required agitation in storage. The writer considered the matter as far back as 1885. In 1904 Mark Spelman suggested a liquid fuel made by pulverising coal in a heavy oil and then thinning the mixture with alcohol. In 1913 Herman Plauson, of Petrograd, Russia, made a true colloid of coal in oil by intensive grinding in a disc mill with or without a soap or rubber solution. It is reported that he successfully burned this fuel in a Diesel engine. To obtain a fuel simple to manufacture in large quantities using ordinary mechanism common to the pulverising art was, however, a much more difficult problem."

In a subsequent paper on Colloidal Fuel, presented at a meeting of the International Railway Fuel Association, Chicago, 1922, the same writer gives an idea as to the comparatively simple plant required for the making of colloidal fuel, thus :—

" The plant necessary for colloidalising is comparatively simple and inexpensive. It is estimated that a plant with capacity to handle 2500 lb. of coal an hour would cost from $35,000 to $40,000, and one with double that capacity about $55,000. The process of manufacture is somewhat as follows. Coal or coke is delivered to a rotary crusher, set to crush to $\frac{1}{4}$ inch, which discharges through a rotary screen perforated with $\frac{3}{16}$ inch by $\frac{1}{2}$ inch slots. The oversize is returned to the crusher by conveyor for crushing. The material passing the screen is carried by bucket elevator to overhead storage bins. From storage the coal or coke (or both) are delivered to a Trump calibrating device, which delivers a predetermined quantity continuously to a steam-jacketed conveyor box or pug mill, which constitutes the receiver and mixer of the tube mill. Oil, tar, and stabilising substance in liquid form, constituting the liquid components to be used, are brought through separate lines to a special measuring device. From this the liquids are delivered to a common discharge line and are pumped through a heater into the pug mill. The liquid and solid ingredients, combined in the pug mill, are fed to the tube mill. There the coal or coke is pulverised in the liquid to the desired fineness. The discharge flows by gravity to heated digesting tanks. From the digesting tanks the finished product is pumped to storage. The measuring devices and pug mill are driven from a common line shaft, so that the feed of the tube mill may be varied at will without disturbing the ratio of solid or liquid feed. The various ratios of coal, coke, oil, tar, etc., necessary for making different grades and natures of fuel can be obtained by changing the initial settings of the measuring devices. The tube mill may be of the Smidt or Allis-Chalmers types. Hardinge and Fuller mills also have been used."

In the same paper Bates summarises his claims as to the advantages attaching to this class of substitute for straight oil.

"The principal technical advantages of Colloidal Fuel are the following: (1) By combining coal or coke, and tar in limited amounts, if desired, with mineral oil, the available quantity of the latter will serve to yield a considerably larger amount of liquid fuel. (2) The fine sizes of coal may be given a profitable use and a liquid fuel value. (3) The heat units in Colloidal Fuel are as efficient as those in oil, and sometimes more so. The reason why in some cases there is greater efficiency may be attributed (*a*) to the explosion of the solid particles when the absorbed liquid vaporises in the combustion chamber, thereby increasing the area for oxidation beyond the surface of atomised droplets, and (*b*) to less flue gas loss, inasmuch as the hydrogen content of Colloidal Fuel (in view of the coal in the mixed fuel) is less than that of straight oil. (4) Since in most localities heat units in coal or coke are much lower in cost than heat units in oil, the cost of heat units in the mixture will be lower than in oil until the cost of oil falls so low that the cost of manufacture balances the economy. This will usually be the case when oil costs about two cents a gallon. For such reasons Colloidal Fuel can compete in most localities with oil. It can compete with coal whenever oil can do so, and sometimes when oil cannot. The cost of manufacture is about one dollar a ton. When crude oil is used and the product is topped, Colloidal Fuel has a further advantage. (5) Since the specific gravity of Colloidal Fuel carrying several per cent. of coal is greater than that of water, a conflagration can be extinguished with ordinary fire appliances and water. It is also possible to fireproof the fuel in storage by a layer of water on the top surface. This is a feature which has been patented. It means that Colloidal Fuel can enter cities where for fire reasons oil cannot without risk or special precautions. There is, therefore, a wider market for Colloidal Fuel than for oil. (6) Owing also to the high specific gravity, the mixed fuel in which a good grade of coal or coke is used possesses greater heat value per unit volume than oil, although showing less per unit weight. Like oil, it possesses, of course, much greater heat value per unit of volume and weight than coal. Fewer barrels or cars of Colloidal Fuel are required than of oil to give the same number of heat units. Where storage space is of importance, as it is on ships and locomotives and in houses, the greater 'heat density' of Colloidal Fuel is of distinct advantage."

It is, of course, admitted that with oil firing, working conditions as we know them approach the ideal. An operator has but to open the valves controlling the flow of liquid fuel drawn from a tank placed in convenient access to the boiler or furnace plant, to regulate his fuel and air supplies so that combustion occurs under smokeless conditions, and thereafter to make occasional adjustments as the temperature of a furnace increases, or as the load of a boiler fluctuates.

Liquid fuel, which is so readily applied and the combustion of which is regulated by easy and convenient methods, would become very much more extensively used in many countries were it not for the prohibitive price and uncertain supply. In countries such as Great Britain, France, Belgium, etc., where there are no known

sources of natural oil of any quantity, but solid fuel—coal, lignite, peat—may be said to abound, it is unlikely that imported liquid fuel will be more extensively used unless, at all events, the cost of fuel oil can be appreciably lowered.

A substitute mixture for straight fuel oil appears to be the only way at present of providing a liquid fuel at a reasonable price.

By mechanically or chemically combining pulverised coal with liquid fuel a resultant is obtained having the desired qualities of liquid or semi-liquid fuel at a much lower cost than straight oil. As against both natural fuel oil and pulverised coal the combination of the two in oil–coal mixtures has many advantages, as, for instance :—

Convenience both of storage and of methods for effecting deliveries.

Fire risks are less than for the oil prior to its mixing with the pulverised coal.

Tank storage as for oil fuel.

No special mechanical equipment required for burning the fuel; the usual pumps and burners and heaters used for oil are, as a rule, equally suitable for colloidal fuel.

Doubtless pulverised coal in itself will be less costly than its equivalent heat value in a colloidal mixture, when the quantity required is sufficient to warrant the erection of a milling plant, or even in the case of small requirements met by periodical deliveries from a central depot, but there will be many occasions when the use of colloidal fuel will present a more attractive proposition.

Just in the same way that small quantities of pulverised coal are obtainable from established pulverised fuel supply companies, there should be equal facilities for obtaining occasional or regular deliveries of colloidal fuel. In view of the ease and convenience with which the latter can be handled, and the absence of danger from fire or explosion, the general use of colloidal fuel should be encouraged, and a demand for supplies be created amongst small consumers who wish to reap the advantages of oil firing but cannot afford to pay the prices usually asked for straight oil.

Liquid fuel supplies could be greatly augmented by the systematic distillation of solid fuel at low temperature, thereby realising appreciable quantities of light oils, motor spirit, lubricants, heavy residual "fuel oil," tar, and valuable fertiliser chemicals. The carbonised residue could then be used either as a smokeless domestic fuel, or as pulverised fuel, or it could be pulverised and remixed with the fuel oil and tar, which are recovered by the distillation process, imported fuel being added to supply the balance required to produce a colloidal fuel of the desired constitution.

The difficulty experienced in blending any solid pulverised combustible with liquid fuel has been in the stabilising of the resultant mixture, as previously mentioned. Bates has discovered a reagent or fixative which greatly prevents the tendency to sedimentation, and many groups of colloidal fuel mixtures have been successfully stabilised through the introduction of the Lindon Bates fixative. The following are some of the mixtures for which figures are given for original

B.Th.U. values of the fuel, and for resultant mixtures of oil and coal, both the original with and without the Lindon Bates fixative.

Fuel.	B.Th.U. per lb.	Sp. gr.	Relative B.Th.U. value per unit volume.
Heavy fuel oil	18,330	0·900	16,497
With 20% soft coal, no fixative	17,307	0·968	16,753
With 25% hard coal, no fixative	16,390	0·995	16,308
No. 1 U.S.A. Navy oil	18,669	0·924	17,297
With 30% soft coal and Bates fixative	17,023	1·035	17,619
Straight soft coal	13,974	—	—

The amount of fixative used for stabilising a 30% coal mixture is about 2·5% by weight. Such a fuel would be heated to about 158° F. in order to render the same sufficiently fluid to pass through the valves and passages of standard oil burners having orifices of $\frac{1}{8}$ in. diameter, at a pressure of 70 to 80 lb. per sq. in.

In the report issued on this subject a comparison is made between the volumetric values of liquid fuel, coal and colloidal mixtures, thus :—

"Assuming a volume of 3 cubic feet of colloidal fuel, of which 2 cubic feet would be oil and 1 cubic foot pulverised coal. The fuel oil weighs approximately 58 lb. per cubic foot, and the heat value, for example, is estimated at 19,000 B.Th.U. per lb. Therefore, 2 cubic feet will contain 2,204,000 B.Th.U. One cubic foot of solid coal weighs approximately 80 lb., and, assuming an average B.Th.U. value of 14,500, 1 cubic foot of coal would contain 1,160,000 B.Th.U. Therefore, a combination of the two fuels, oil and coal, and in the ratio of 2 of oil and 1 of coal, would contain 3,364,000 B.Th.U. or 1,121,333 B.Th.U. per cubic foot, as compared with only 1,102,000 B.Th.U. per cubic foot of oil. The heating values will vary directly, according to the B.Th.U. value of the coal and the oil."

It will be seen, therefore, that the colloidal fuel containing the fixative will sometimes have a greater calorific value than straight oil per unit of volume but a lower value per unit of weight, and depending upon the relative specific gravities of the materials used. Further information relating to the Bates process is given at pp. 124 to 129.

Use of Colloidal Fuel for Locomotive and Marine Purposes.

From this it may follow that colloidal fuel will become a class of fuel of favour not only for industrial uses, but especially for maritime work, and in particular for small craft where bunker space is limited. Even greater possibilities are perhaps presented for locomotive use. Some conclusive tests have been made in this direction on the Great Central Railway, England, by J. G. Robinson, late Chief Mechanical Engineer of that railway, who used mechanical mixtures of coal and oil without any addition of fixatures.

As a locomotive fuel, colloidal oil will have all the special features of oil firing,

viz., smokeless operation, reduced back pressure on cylinders with consequently greater engine power, rapid and clean bunkering conditions, no firing tools, increased steam in boiler and complete control of steam generated, increased life of loco boiler, no time lost in cleaning out the firebox and smokebox. In stating these advantages it is presupposed that colloidal oil mixtures can be made at a cost showing an attractive saving over straight oil, otherwise the cost of plant for production of the special fuel will introduce a capital charge non-existent when straight oil is used.

Mixtures containing up to 50% coal can be so made as to show little tendency to subsequent separation, and for all intents and purposes for industrial uses these appear to be just as good as the chemically " fixed " compounds. Moreover, the sedimentation that may occur with straight mechanical mixtures can, as a rule, be readily remixed by rotation of the container drum, or by pump circulation of any large bulk of fuel. This remixing of deposit may not be an easy matter, even if in some cases it be possible at all, for chemically fixed mixtures, the deposit from which may be of such a glutinous character that remixing becomes quite out of the question.

For this reason the storage of any colloidal mixture in ships' bunkers which may be inaccessible, or in double bottoms, cannot be advocated without reserve. The larger the proportion of solid fuel the greater the degree of sedimentation, and it would appear from present knowledge that marine fuel should perhaps be limited to between 20% and 30% of pulverised coal.

For bunkering on board ship it would appear that either a mixture containing the lower percentage of coal must be used, or it may be possible to bunker colloidal fuel approaching the gelatinous state and containing 60 or 70% of pulverised coal. Fuel of this nature would be semi-solid, and could be stored for breaking down prior to use with straight fuel oil carried in the more out-of-the-way bunkers.

It can be readily understood that apart from any special consideration of convenience or particular advantages, the general use of colloidal fuel will be governed by the relative cost of solid and liquid fuel available.

Under normal conditions therefore colloidal mixtures *per se* do present certain advantages, such as, for instance, the convenience of storage and acceptance of supplies, the reduction of fire risks, owing to the higher flash point of colloidal fuel, simple mechanical equipment on site, ordinary tanks, pumps and burners.

Pulverised coal is obviously less costly than a half and half oil-coal mixture, but, small consumers wishing to use pulverised coal cannot always instal complete preparation plant. In America there are one or two central supply companies delivering pulverised coal to users in their respective districts. In similar manner distribution of colloidal fuel could be undertaken with profit when market prices of coal and liquid fuel are suitable and sufficiently stable.

Comparison of Colloidal Fuel and Pulverised Fuel.

Upon the question of savings to be effected and the cost of equipment for pulverised coal or colloidal oil, it may be of interest to cite a hypothetical case. Assume

a small power-house boiler plant consisting of two 30 ft. by 8 ft. Lancashire boilers:—

Maximum load, 1200 kw. Average load, 900 kw. for 12 hours per day; 300 kw. for 12 hours of night.

Evaporation per boiler, 6500 lb. per hour (hand-fired coal).

Steam pressure, 160 lb. sq. in. Superheat, 100° F. Feed water temperature, 120°F.

Calorific value of fuel (coal), 12,000 B.Th.U. per lb.

Hand-firing efficiency, 65 % (unusually high).

Pulverised coal-firing efficiency, 75% (normal).

Colloidal fuel-firing efficiency, 75% (normal).

Total heat required per lb. of steam, 1116 B.Th.U.

Effective heat of fuel (75% efficiency) for pulverised coal firing, 9000 B.Th.U. or 7·72 lb. of steam per lb. of coal.

Fuel consumption per boiler, pulverised coal firing, per hour, 843 lb.

With hand firing, effective heat of fuel (65% efficiency) is 7800 B.Th.U.

Fuel consumption per boiler, 970 lb. per hour.

The load on the station is 14,400 kw. hours per day and night, and assuming a steam consumption of 18 lb. per kw. hour, 259,200 lb. of steam will be required per 24 hours, or

Fuel consumption (hand firing), 38,750 lb. per 24 hours.

Fuel consumption (pulverised coal firing), 33,550 lb. per 24 hours.

A daily saving of 5200 lb. of coal.

Taking a year, equal to 300 working days, the fuel saving due to pulverised coal-firing would amount to approximately 700 tons.

Say, for the sake of argument, coal for hand firing costs 35*s.* per ton delivered at the stokehold, and coal for pulverising can be purchased at 25*s.* per ton, owing to the smaller grade of coal usable for this purpose. Also assume that the overall preparation and application cost for pulverised coal in this relatively small quantity is 7*s.* 6*d.* per ton, making a net saving in cost of fuel of 1*s.* 6*d.* per ton over hand-firing, exclusive of reduction of labour, etc. The cost of 5190 tons of coal at 35*s.* for hand firing = £9082 per annum, and for pulverised coal firing at 33*s.* 6*d.* per ton for 4493 tons = £7525, or a saving per annum of £1557. The approximate cost of complete pulverised coal equipment would be in the neighbourhood of £8000.

On the other hand, pulverised fuel could be purchased, no doubt, from a supply company at an overall price of less than 33*s.* 6*d.* per ton, for the burning of which the capital expenditure on necessary equipment would not amount to more than about £2000. Under the latter conditions the burning of fuel in pulverised form would be a very paying proposition for the size of plant stated.

In like manner, if we consider the purchase of a 16,000 B.Th.U. oil-coal mixture, giving 12,000 B.Th.U. effective heat value, from a supply company at a price of, say, £2 17*s.* 6*d.* per ton—a sufficient price in comparison with that of straight oil—one

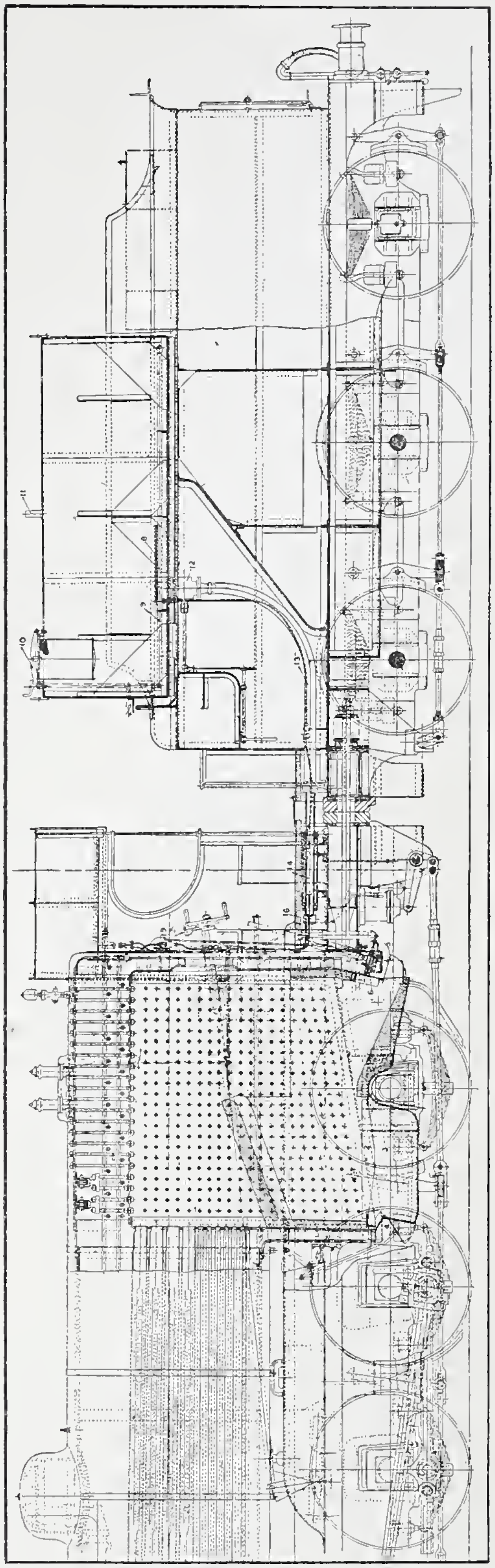


FIG. 12.—Great Central Railway Goods Locomotive fitted with Robinson Equipment for burning Colloidal Fuel. (*Modern Transport.*)

would require 3369 tons of oil coal or colloidal fuel, costing £9685, which would be rather more than the cost of fuel for hand firing, but one would gain considerably in overall economy of the station. Moreover, the actual burner equipment would be little more than, say, £1000 for this purpose, inclusive of storage drums.

Experiments on Great Central Railway.

It has been suggested above that colloidal oil mixtures should prove to be of exceptional value as fuel for firing locomotive boilers.

Fig. 12 shows the G.C.R. locomotive as equipped for burning colloidal mixtures to the designs of J. G. Robinson, and the brief description of this engine is as follows (*Modern Transport,* June 3rd, 1922) :—

This locomotive, as previously mentioned, has been fitted for burning liquid fuel or mixtures consisting of ordinary fuel oil and pulverised low-grade fuel. In this arrangement the front half of the brick-lined firepan (1) is fitted with firebars (2), on which is strewn a thin layer of broken fire-brick, air being admitted through this to the firebox under the action of the blast pipe or blower. This air supply is controlled by the damper door (4), which is operated from the footplate. At the rear end of the firepan is a second damper door (5) controlling a further supply of air below the burner. The burner (6) is of the triplex type, consisting of three identical fuel injectors and atomisers in one body. The steam connections are so arranged that the central burner alone, the two outer burners, or all three can be worked. The injecting and atomising steam jets of all three combinations are separately controlled. The fuel is stored in a rectangular tank (7), which is provided with a manhole

(10) and vent pipe (11). A steam warming coil (8) serves to reduce the viscosity of the fuel in cold weather, and a compressed-air pipe (9), perforated with a number of small holes, is fitted for the purpose of agitating the fuels and ensuring their intimate mixture. The fuel is drawn off from the tank by the plug cock (12) and flexible pipe (13) to the heater (14). The heater is an annular vessel containing circulating steam supplied from the combination fitting (15) on the fire-box back. The fuel passes along the pipe (16), which is provided with two branches —one leading to the regulating cock (17) and central jet of the burner, and the other to the regulating cock (18) and two outer jets of the burner. Hand levers and quadrants (19 and 20) controlling these regulating cocks are conveniently placed on the firebox back plate.

As it has been found more economical to use superheated steam for atomising purposes, a special superheater element, independent of the superheater, is connected to a combination fitting (15), which is so arranged that either superheated or saturated steam can be readily distributed to the burners, the preheater in the tank and on the foot-plate. Steam is taken from the fitting (15) by the pipe (25), to the tee fitting (26), and thence to the two duplex stop valves (27 and 28). The stop valves of the upper pair (27) control the front and central steam supply of the central jet, and those of the lower pair (28) control the steam supply to the two outer jets of the burner (6). Steam is supplied to the heater (14) and the warming coil (8) in the fuel tank by control valves (29 and 30 respectively). In order to operate the jets when raising steam, a pipe (31), fitted with unions for connecting it to an external steam supply, is provided. This pipe is connected to the combination fitting (15) through stop and non-return valve (32). Outside steam is prevented from entering the boiler via valve (21) or by the superheated steam pipe by the two non-return valves (21 and 22 respectively). At the same time the non-return valve (32) prevents any flow of steam from the boiler of the locomotive to the external source of supply when the pressure in the boiler exceeds that of the external supply. The cock (33) controls the supply of steam from the external source to the ordinary blower and circulating valve (34) which is provided with a non-return valve to prevent the external steam from entering the boiler.

Various types of mixtures have been used for fuel on this locomotive, the following being examples. One mixture consisted of 50% Elsecar coal dust, 37·5% creosote and 12·5% pitch, the whole giving a calorific value per lb. of mixture of 15,241 B.Th.U. Another mixture consisted of 50% Elsecar coal dust and 50% fuel oil, giving a calorific value per lb. of mixture of 16,700 B.Th.U. A third, consisting of 60% Elsecar coal dust and 40% fuel oil, gives a calorific value of 16,427 B.Th.U. per lb. of mixture, and a fourth, consisting of 50% coke breeze and 50% fuel oil, one of 15,708 B.Th.U. A still further mixture, comprising 65% smokebox ashes and 35% fuel oil, gives a calorific value varying according to the value of the recovered smokebox ashes. All these mixtures have been tried, with satisfactory results, but the following particulars, compiled as a result of a test with the third mixture named (60% Elsecar coal dust and 40% fuel oil), will serve to indicate the possibilities of this type of apparatus.

Method of preparation	Mixed by air.
Moisture	1·15%.
Ash	4·40%.
Combustible matter	94·44%
Calorific value of fuel	16,427 B.Th.U.
Total water used	26,700 lb.
Total fuel consumed	2965 lb.
Evaporation per lb. fuel	9·01 lb.
Factor of evaporation	1·35 lb.
Equivalent water evaporated from and at 212° F.	12·16 lb.
Overall efficiency	72%.

Lindon Bates Process (Further Notes).

As this particular class of semi-liquid fuel in the form of coal dust and oil mixtures has been so thoroughly investigated, and placed at the disposal of the engineering and industrial public, through the energetic work carried out by Mr. Bates, the author feels justified in emphasising the valuable characteristics of colloidal fuel, and to a certain extent repeating some of the facts already recorded. Permission has, therefore, been obtained to reprint the concise review which has been given in *The Times Engineering Supplement*, November, 1920, dealing with the "Characteristics and Properties of Colloidal Fuel," thus :—

"Of two papers read before the Institution of Petroleum Technologists, one, by Lindon W. Bates, gave a general account of the material, while the other, by Haylett O'Neill, supplied more detailed data about its properties and characteristics.

"Colloidal fuel is described as a stable, mobile, atomisable fuel displaying colloidal characteristics, comprising particles of solids, droplets of liquids, or minute bubbles of gas suspended in one or more varieties of liquid hydrocarbons. For commercial purposes it contains 25 to 40% of pulverised coal, which is held in stable suspension in oil, so that the product can be handled and fired with the usual oil-burner apparatus. The object of combining solid with liquid fuel is to utilise the cheaper heating values of the former and yet retain the fluid advantages of the latter, the result being that the value of the carbon is increased without decreasing the value of the liquid.

"The fuels available vary in different parts of the world. In Great Britain practically all the imported heavy petroleum oils are usable. When such oils are employed, and yet a fuel of high fluidity at normal temperatures is desired, a cut-back or a thinning oil may be added. When tar and tar products are less expensive per unit of heating value than oil, and have the desired viscosity characteristics, they may be used in combination with oil. A purely coal-bearing country may, therefore, produce a considerable portion of its own liquid fuel supply. In some instances certain tar products may even serve as the principal liquid component; for example, colloidal fuel has been successfully made from crude oil and wax tailings, thinned with pressure-still oil or tar. Carburetted water-gas tar is also a useful cut-back.

"The solid components may be coal, coke, charcoal, hard pitch, or any grindable carbonaceous substance. Within reasonable limits the amount of non-combustible matter in the solid component has little effect on the combustion efficiency. The principal objection to such inert matter is the cost of storing and handling unproductive material, and in a locality where the use of a liquid fuel is economically justified, storage and handling costs usually make it important, if possible, to employ solid matter with low ash and moisture content. For the best results the solid must be ground so that about 97% will pass through a 100-mesh screen and at least 85% through a 200-mesh screen. Though such fineness is not strictly necessary for stability, it is desirable in order to obtain the best combustion efficiency and fluidity.

"A number of methods of achieving stability have been evolved. It is possible to stabilise particles by the use of certain protective substances, such as soap solutions, some of which are operative not only upon colloidal coal in oil, but also upon particles far above colloidal dimensions in size. A typical substance is a specially prepared variety of lime-rosin grease, in which lime, rosin and water are incorporated with heat and circulation into an oil carrier. Again, bituminous coals and some other solid carbonaceous substances can be peptised to a limited but sufficient extent for stabilising purposes by adding percentages of coal distillates, such as tars and the middle fractions, and subjecting the mixture to heat treatment below the flash-point temperature. Thirdly, by intensive grinding it is possible to reduce coal to colloidal size, or practically so, and thus achieve the stability inherent in smallness of dimensions. These and other measures are readily combined so as to adapt the stabilising treatment to the specific gravities, surface tensions, viscosities and association tendencies of the several ingredients.

"The percentage of particles that may settle out during the life of the composite depends upon the treatment given. Experience with the U.S.S. *Gem* in 1918 indicated that practically complete stability for over six months could be expected of a 31% mixture of Pocahontas coal in fixated navy fuel oil. With 38% of mixed coal and coke in fixated Mexican oil only 2·6% of the particles were found to have become destabilised in five months. Grade 16 of the fuel, with 42% of mixed coal and coke in fixated Mexican oil, was successfully burnt eight months after manufacture, though it had been exposed in the open air to frost and weather, without any motion treatment other than that necessarily involved in coil-heating and removing the material from the barrel. A fuel with 42% of coal made in the United States at the beginning of October, 1919, and shipped to England in barrels, showed substantially no settlement a year later.

"Colloidal fuel is often volumetrically richer in heat units than straight oil. Though in it oil is associated with carbon of a lower heat value, and therefore the product contains fewer heat units per lb. than oil, the higher density of the composite results in its possession of more heat units in a given volume than coal. Its specific gravity is greater than that of water. For example, colloidal fuel made from 65% of oil of 18,500 B.Th.U. per lb. (177,600 B.Th.U. per Imperial gallon) and 0·96 specific gravity and 35% of bituminous coal of 14,000 B.Th.U.

and 1·4 specific gravity, is heavier than water and has 182,000 B.Th.U. per gallon. A special grade of navy fuel using crude oil coke of 15,000 B.Th.U. and 1·8 density will have 198,600 B.Th.U. per gallon, or 12% more than the oil. Where storage space is of importance and weight is of less consequence greater heating capacity and steaming capacity can be obtained by using the composite, and much greater than by using coal. A property of colloidal fuel related to this compactness is its low-temperature coefficient of expansion. As coal shows practically no expansion with heat, the coefficient of expansion of the composite is less than that of oil in the proportion of the percentage of coal used.

"The fuel may be stored in ordinary oil tanks, and will not corrode the tanks, pipes, or valves more than ordinary oil, as it is slightly alkaline and does not affect iron or other metals. A feature of great importance in connection with its storage is that it is practically non-volatile. With ordinary fuel oil the loss by evaporation will average up to about 8% per year; in other words, if the market price of money is 7% interest yearly, the investment value tied up in naval oil storage really costs the taxpayers about 15% interest on account of the evaporation losses. As colloidal fuel is heavier than water, oil evaporation can be entirely prevented by covering the surface with a sheet of water. Another slight loss that would undoubtedly be reduced is the seepage, since the fine coal particles would tend to force themselves into the seams and caulk them.

"Since the colloidal fuel coal component has a specific heat of less than 0·25, while oil has a mean specific heat of about 0·5, colloidal fuel itself has a lower specific heat than oil. This means that to heat it to the proper temperatures for fluidity and atomisation less fuel heater surface and less heating steam is required. Thus, if 500 tons of oil are heated from 40° to 200° F., approximately 100,000 lb. of heating steam per day are required. To heat a quantity of colloidal fuel, having the same heating value, containing 35% of coal, would require 85,000 lb. of steam. The saving in heating steam would then be 15,000 lb. or about 15% and the saving in heater surface would also be 15%.

"Tests of colloidal fuel show that the unburned carbon in the refuse may be nil, and experience indicates that the excess air need be no greater than with oil. This means that the flue-gas loss with colloidal fuel will be less by several per cent. than that for oil, because the loss from superheated steam at flue-gas temperature, due to the burning of hydrogen in the colloidal fuel, is less than with straight oil. Since the coal component of the fuel contains approximately 5% of hydrogen, while straight oil contains about 13% colloidal fuel carrying 35% of coal contains approximately 10% of hydrogen. At 500° F. flue-gas temperature, the B.Th.U. loss on account of hydrogen per lb. of colloidal fuel equals 1160 B.Th.U., while for the oil it equals 1505 B.Th.U. The difference in favour of colloidal fuel is 345 B.Th.U., or nearly 2%.

"There is evidence that the efficiency of colloidal fuel is improved by the surface combustion effect of the myriads of finely divided solid particles, either of burning carbon or of white-hot ash, widely dispersed through the gas and throwing off their radiant heat. This is a condition favourable to quicker combustion, and moreover there is a direct radiation of heat to the boiler heating surface.

"Moisture content within reasonable limits affects the efficiency very little. Since the fuel can be made containing not more than 1% of moisture, the loss in this case will be only 10 B.Th.U., or approximately 0·06%. With straight oil fuel as little as 3% of moisture may cause considerable loss in efficiency and inconvenience, due to the tendency of the water to separate. With oil fuel there is danger of flooring the burners with plugs of water, which may temporarily put out the fire, which is later revived with an accompanying gas explosion of varying magnitude. Owing to the impossibility of separating the 1·0% of emulsified water from colloidal fuel, this fuel offers a complete relief from moisture trouble with little effect upon efficiency. Colloidal fuel made with 35% coal of 10% ash content contains only about 4% ash.

"Regulation tests at sea and on land indicate that the efficiency of colloidal fuel for steam-raising purposes is at least equal to that of oil, and certain grades have shown superior efficiencies. In general the efficiencies of oil and colloidal fuel may be taken as substantially the same.

"As colloidal fuel is practically non-volatile and can be fire-proofed by means of water seal, which will not emulsify with the fuel, the dangers from gas explosions of liquid fuel can be eliminated. Moreover, the flash-point of the composite is never less than that of its constituents, and usually it is higher. In a striking case a crude Panuco oil and a water-gas tar having respective flash-points of 130° and 170° F. were specially blended with soft coal, and the result was composite fuel with a flash-point of 270°.

"There is no danger of loss from spontaneous combustion in the case of colloidal fuel as with stocks of bituminous coal. It is possible to protect from fire a tank filled with the composite by chemicals such as froth, but a water seal or a stream of water is as effective and far more simple. Nor is there the same danger present in a ship's fire-room when colloidal fuel is used, should the bunker tanks, springing a leak, admit oil and water, upon which the oil would float and, as has often happened, take fire with disastrous results. Colloidal fuel, being heavier than water, in such a case would be drowned before it could take fire. Being non-volatile, should the fuel escape from a leaky pipe in the pressure system, and be exposed to fire, it would at most burn without liberating inflammable gases.

"By using colloidal fuel there is a financial gain of a few per cent. on account of storage efficiency over straight oil, owing to its higher heat capacity per unit of volume and in its freedom from evaporative loss. Suppose that a navy had a reserve oil storage of 1,000,000 tons, which lost by evaporation even as little as 6% per year, or 60,000 tons, at 120*s*.[1] per ton the loss would amount to £360,000 per year. All of this could be saved if the reserve oil were replaced by colloidal fuel.

"The big factor of colloidal fuel economy is the saving in cost per given number of heat units over those of straight oil, because the coal component is much cheaper than the oil component. For example, with a colloidal fuel composed of 65% of oil having a specific gravity of 0·96 and 18,500 B.Th.U. per lb., costing 1*s*. per Imperial gallon, and 35% of coal, 1·4 specific gravity,

[1] 120*s*. per ton represented a "War" price. Normal price of oil fuel about half.

14,000 B.Th.U. per ton, and 40*s*. per ton, the cost per million B.Th.U. will be 4*s*. 6·25*d*., allowing 6*s*. per ton of manufactured product, while with oil fuel it will be 5*s*. 7*d*. per million B.Th.U. The oil will cost 35*s*. per barrel, and the cost of an equal heat-content in colloidal fuel will be 28*s*. 1*d*., a saving of cost of 6*s*. 11*d*., or nearly 20%. The manufacturing cost, though it will naturally vary with local conditions, may safely be taken to be within 10*s* per ton of product in Great Britain for a plant of over 150 tons output a day."

Characteristics of the Bates colloidal mixtures are shown in the following table :—

Example.	%.						
	A.	B.	C.	D.	E.	F.	G.
Paraffin Base Oil	70	—	10	10	8	—	—
Asphaltic Base Oil.	—	—	—	30	—	60	54
Pressure Still Oil	—	35	37	30	50	4	4
Wax Tailings	—	—	3	—	—	—	—
Coal Tar	—	20	—	—	10	—	—
Middle Fraction Coal Oils	—	10	—	—	2	—	—
Road Oils	—	—	10	—	—	—	—
Anthracite Coal	—	—	38	—	—	—	—
Bituminous Coal	30	35	—	30	30	18	21
Coke	—	—	—	—	—	18	21
Fuel Specific Gravity	1·03	1·12	1·15	1·08	1·04	1·05	1·08
Fuel Flash-Point (Open Cup) ° F.	240	250	300	266	262	273	280
Fuel B.T.U. (per lb.)	17,100	17,000	15,300	17,200	16,650	16,900	16,700
Viscosity (° Engler) 70° to 100° F. (° E.).	170	350	200	67	452	—	—
Suitable Preheat (° F.)	150	160	150	150	180	180	180
Stability (Minimum at 70° F.)	3 months	3 months	10 days	4 months	4 months	6 months	8 months

The specific gravity of colloidal fuel may be calculated by the formula given by Haylett O'Neill :—

Specific gravity = (100 × specific gravity of coal × specific gravity of oil) divided by (per cent. oil × specific gravity of coal + per cent. coal × specific gravity of oil).

The specific gravity of colloidal fuel containing more than two components—as, for example, oil, tar and coal—each of a different specific gravity, may be expressed by :—

(100 × specific gravity oil × specific gravity coal × specific gravity tar) divided by (per cent. coal × specific gravity oil × specific gravity tar + per cent. tar × specific gravity coal × specific gravity oil + per cent. oil × specific gravity tar × specific gravity coal).

The B.Th.U. per lb. of colloidal fuel may be expressed as follows :—

(Per cent. coal × B.Th.U. per lb. coal + per cent. oil × B.Th.U. per lb. oil) divided by 100.

The heat content per unit of volume depends upon the B.Th.U. per lb. of the coal as well as upon its specific gravity. The higher the quality of coal and the

greater its specific gravity, the greater will be the volumetric heat content of colloidal fuel. Hence, where the storage is limited, low ash coals of a fairly high density should be employed. The heat content of colloidal fuel per imperial gallon = 10 × specific gravity × B.Th.U. per lb., namely :—

(10 × specific gravity coal × specific gravity oil) divided by (per cent. oil × specific gravity coal + per cent. coal × specific gravity oil) × (per cent. oil × B.Th.U. per lb. oil + per cent. coal × B.Th.U. per lb. coal).

The heat content per cu. ft. of various fuels as compared with colloidal fuel is shown by the figures tabulated below :—

HEAT DENSITY OF VARIOUS FUELS.

Fuel.	B.Th.U. per lb.	Cu. ft. per ton.	B.Th.U. per cu. ft.	Relative Heat Density.
Colloidal fuel	16,675	33·3	1,115,232	100·0
Topper Mexican oil	18,500	37·5	1,106,300	99·2
Anglo-Persian oil	18,990	40·3	1,055,000	94·6
Paraffin	19,728	44·2	999,736	89·6
Petrol	19,962	51·6	870,543	78·1
Scotch coal	13,800	46·2	669,000	60·0
Newcastle coal	14,300	49·8	645,000	57·8
Welsh coal	15,000	54·6	615,000	55·1
Pulverised Scotch coal	15,000	56·0	600,000	53·8
Acetylene gas	21,850	32,600	1,502	0·0013
Carburetted water gas	12,888	41,500	650	0·0006
Hydrogen	61,500	423,000	325	0·0003
Producer gas	1,929	32,200	134	0·0001

For the production of colloidal fuel of the highest calorific value the inert material in coal should be extracted to the fullest extent. If poor grades of coal and waste mine dump, for instance, are to be used for the purpose of colloidal fuel mixtures, there can be no better method of extracting the dirt and unburnable material than by either the Froth Flotation process (p. 108) or the Trent system of cleaning coal.

Application of Colloidal Fuel. Calvert Apparatus.

From the foregoing notes on colloidal mixtures it will be understood that whereas the Bates fixative tends to maintain the two fuels in solution and to prevent sedimentation, yet for ordinary purposes the use of fixatives is unnecessary. Furthermore, as a marine fuel the glutinous deposit that may result from a "fixative" colloidal fuel may present serious bunker troubles.

The simple method of continuous circulation of a straight oil-coal mixture, when bulk supplies are held in storage, has been incorporated in patents taken out by G. C. Calvert in 1920. Calvert aims at providing a ready means of preventing sedimentation, both by heating or aerating the fuel in the container tanks, and by adopting a flow-and-return system through which the fuel is continuously pumped; branch pipes are connected up to small rotary pumps, which "milk" the main supply and feed the furnace burners.

Fig. 13 shows a Calvert arrangement for a boiler installation with one fuel tank. Fig. 14 shows the circulating system as suggested for two fuel tanks. Fig. 15 shows the Calvert system as suggested for use on board ship.

In each of these illustrations 1 is the container tank, 2 the colloidal fuel through which air, gas or steam can be passed from the ring 3, so that the lower or thick

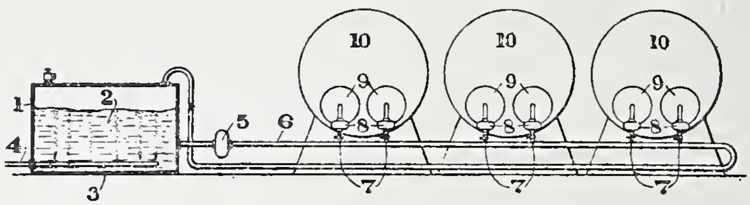


Fig. 13.

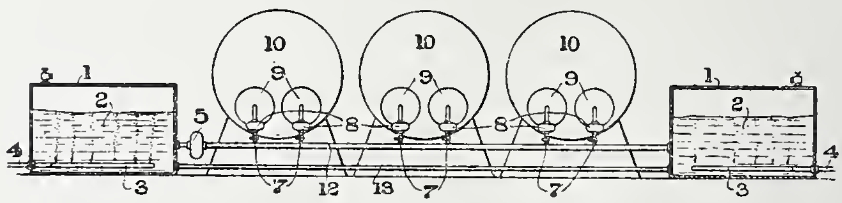


Fig. 14.

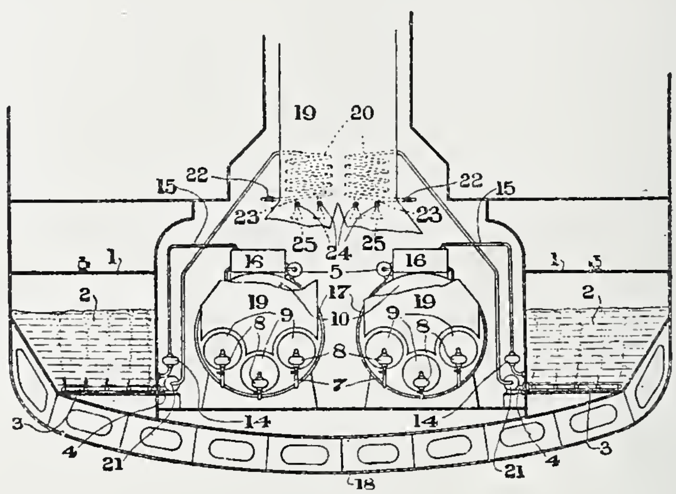


Fig. 15.

Arrangement of Colloidal Fuel Heaters and Circulating System. (*Calvert Patents.*)

layers of fuel can be warmed. The gas or steam is admitted through the pipe 4. Fuel is pumped through the supply main 6 by the rotary pump 5. Similar and smaller pumps 8 feed the fuel through the branch pipes 7 to the burners.

In Fig. 15 a subsidiary tank is shown above the boiler to which fuel is supplied by the pump 5, and from which, by means of auxiliary pumps 9, the fuel is forced through the main supply pipe 6 back to the subsidiary tank, branch pipes to the burners being arranged as described. Hot waste gases can be withdrawn from the uptake by means of the rotary fan 10 for passing into the heater ring 3.

It would appear quite unnecessary to fit so many small rotary pumps which would have to be mechanically or electrically operated. The system well illustrates the possibilities of circulation to obviate sedimentation in bulk supplies.

Colloidal fuel should be eminently suitable, at a reasonable price, for use in iron, steel and brass foundries and for general furnace-heating work.

Arranged upon some such lines as the above, a range of crucible furnaces could be conveniently fired with colloidal fuel tapped from a loop circulating main, and it is well known that plumbago crucibles heated in oil-fired furnaces have double the life of similar capacity crucibles heated in coke-fired furnaces, providing the liquid fuel used has not a high content of hydrogen.

Colloidal fuel should provide the particular factors necessary to ensure long crucible life, whether used for iron, steel or brass.

CHAPTER VII

LOW-TEMPERATURE CARBONISATION OF COAL

Recovery of By-Products—The Smith Process—Distillation of Brown Coal—The Fixation of Gas from Pulverised Coal—Benner and Lewes Processes.

In the opening remarks contained in the Introduction to this book it is contended that the use of pulverised coal should be considered in conjunction with, and not in opposition to, the treatment of fuel by distillation processes, in order to recover valuable coal products, provide smokeless fuel for domestic and industrial purposes, and suitable by-product coke containing sufficient volatile material for pulverisation and burning in this form to maximum advantage.

A complete fuel-handling, preparing, and applying plant on any comprehensive scale should embrace several sections, viz. for :—

(*a*) The washing of high ash fuel preparatory to further treatment and burning in any form whatsoever.

(*b*) The partial distillation of volatile constituents, provided that the market for the distillates recovered warrants the adoption of this process. The process of distillation should be so balanced that the gas produced is no more than sufficient for the heating of the retorts, so that no appreciable amount of gas is wasted.

(*c*) The subsequent gasification of a portion of the coke produced for the supply of gas to small types of furnaces; and the utilisation of the bulk of the coke in pulverised form, or as a smokeless domestic fuel.

Such a scheme would entail the erection of Washery Plant; Low-Temperature Distillation Retorts; By-Product Recovery Plant; Gas Producers for subsequent Gasification of Coke; Pulverised Coal Mills (no dryers should be required); Conveyor Systems; and Fuel Burners.

Recovery of By-Products.

From each ton (2240 lb.) of average bituminous coal containing, say, 8 % ash and 22 % volatile matter, the approximate return from a low-temperature (450° C.) distillation plant, as installed to produce a coke suitable for pulverisation, would be about :—

Gas of 550–600 B.Th.U.	2500 cu. ft.
Coke (smokeless fuel)	1700 lb.
Heavy tar (sp. gr. 1·06)	40 ,,
Light oil (sp. gr. 0·95)	105 ,,
Motor spirit (sp. gr. 0·85)	35 ,,
Sulphate of ammonia	20 ,,

The resultant coke, or smokeless fuel, from the above plant would contain about 8 % volatile matter, 80 % fixed carbon, and 12 % ash.

Certain grades of coal are naturally more suitable for subjection to low-temperature distillation than others : anthracite coal would return practically nothing in the shape of by-product other than coke, whereas cannel coal is exceptionally rich in volatile constituents. The ordinary run of bituminous coal will show a result in proportion to the volatile material it may contain; coal from the Kent coalfields (England) is particularly productive on distillation. A test upon Chislet round coal containing 1·65 % moisture, 22·15 % volatile matter, 74·2 % fixed carbon, and 2 % ash showed the following results :—

Oil of 0·9888 sp. gr. . .	23·5 gals. (approx. 235 lb.) per ton of coal.
Gas produced . . .	3300 cu. ft. (600 B.Th.U.) per ton of coal.
Residue coke	8·9 % volatile matter; 87·6 % fixed carbon; 3·5 % ash.

From a low-temperature (800° C.) distillation plant of 100 tons capacity per 24 hours there could be produced, say, 700,000 cu. ft. of high calorific value gas (600 B.Th.U. per cu. ft.) per ton (2240 lb.) of average bituminous coal. By carbonising the residue coke in gas producers, and enriching the producer gas with the balance of high calorific value gas not required in the process of distillation, an estimate made by the Low Temperature Carbonisation Company indicates that the products available for use or disposal over and above the quantity of gas required for heating retorts, etc., would be as follows :—

2,800,000 cu. ft. of 250 B.Th.U. gas; 70 tons of smokeless coke; 1600 gals. of light oils; 300 gals. of motor spirit; 400 gals. of tar; 2 tons of sulphate of ammonia.

The decision whether it would pay better to carry through the complete carbonisation of fuel, or to stop at partial carbonisation, *i. e.*, low-temperature distillation, depends upon the price of coal and the locality or country in which the plant is to operate, *i. e.*, upon such variables as rate of wages and value of the by-products in the markets available. It also depends upon the quality of coal to be treated. In the main, it may be contended that the complete carbonisation of coal is not the most advantageous. Partial distillation and the production of a semi-smokeless coke ready for use as such, or a coke containing sufficient volatile content to make it easy to pulverise it, and to burn it at nearly 100 % efficiency, appear in very many cases closely to approach the ideal treatment.

The Smith Process.

The Smith Continuous Combination Low and High Temperature Carbonisation System has been received with great interest in America, and, on the results obtained at the Washington Plant, several commercial installations have been made during recent years. Plants having a daily capacity of 100 and 500 tons are now in operation. The product of this system is known as "carbocoal," and is produced in the form of briquettes, or eggettes, as illustrated in Fig. 16.

The process consists of subjecting low-grade crushed coal in a retort heated to a temperature of 480° C. After a distillation period at this temperature, the

semi-coke is ground and mixed with a pitch binder, and pressed into eggettes or briquettes which are charged into a high-temperature retort heated to about 1100° C. The briquettes become dry and hard in this second retort and are withdrawn ready for despatch.

The degree of hardness thus produced not only prevents fracture and loss during transit, but renders the fuel suitable for metallurgical purposes. In an open domestic grate the briquettes can be burned with the same facility as hard coal, there being little smoke and, with washed fuel, little ash: fuel retorted at high temperature would resemble anthracite, and at a lower temperature a softer grade of coal. The demand for marketable domestic fuel can thus be taken into account by operating the retorts in this manner.

Double retorting, with cost of intermediate handling, increases the cost of production, but it is claimed that by so doing the value of the increased bulk of by-products resulting from the dual process, such as oil and sulphate of ammonia, more than covers the additional cost of retorting.

Distillation of Brown Coal.

Professor W. A. Bone in his Cantor lectures before the Royal Society of Arts in 1912 records some very valuable work carried out upon the distillation of brown coal and lignites at the Imperial College of Science and Technology in London. The results of experiments with distillation at various temperatures, 375° to 850° C., establishes the fact that little combustible gas is given off at temperatures below 500° C. Results obtained when working on matured lignite from Canada are given in Table I, while in Table II parallel results are given for matured lignite from Burma.

Table I.

	500° C.	700° C.	850° C.
Residue	69·7	62·0	60·2
Liquor	8·7	10·1	9·5
Oil and tar	2·5	2·9	1·8
Gas	20·3	25·2	29·3

Table II.

	500° C.	700° C.	850° C.
Residue	70·7	60·0	59·0
Liquor	10·3	11·3	9·9
Oil and tar	3·0	3·8	2·2
Gas	15·5	24·0	29·1

Professor Bone negatives the idea that brown coals and lignites are capable of producing large amounts of valuable oils and tars of exceptional value. The quantities likely to be obtained are given in his table reproduced hereunder.

Oils.	Density.	Lb. per ton of Coal.
Light spirits	0·85	13·8
Light oils	0·88	19·8
Intermediate oils	0·95	6·7
Heavy oils	1·0	22·5
Pitch	1·1	23·7

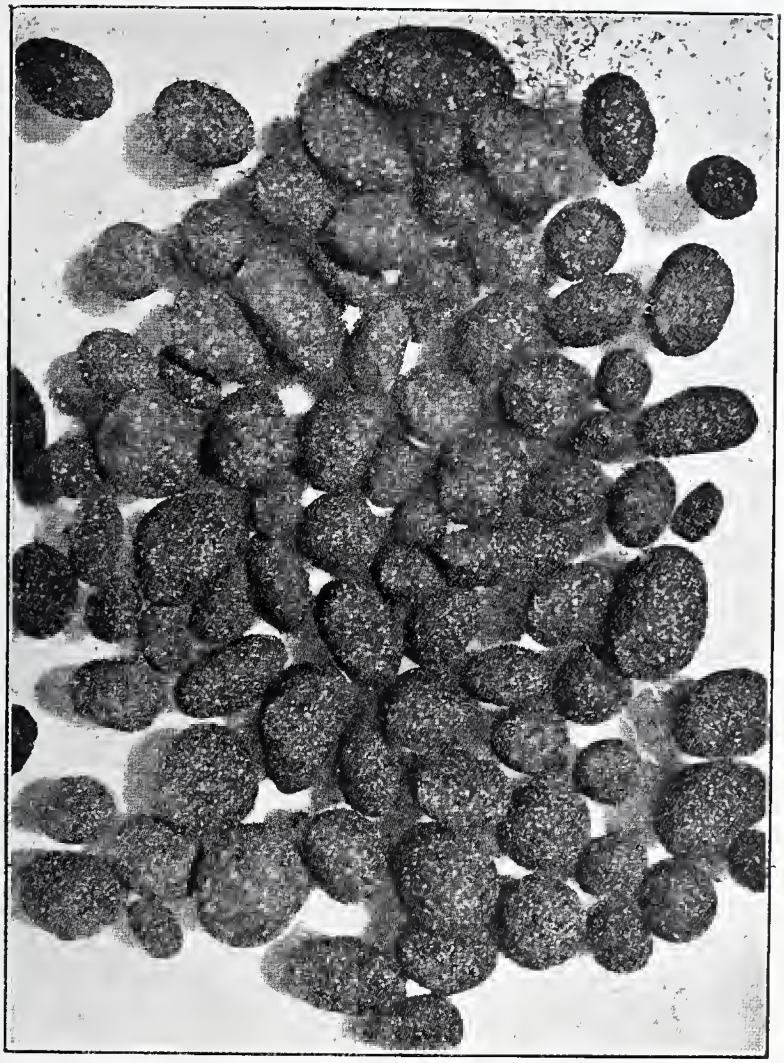


Fig. 16.—Lumps of Oil-Coal Amalgam (actual size): Smith or Trent Process.

Power, August 2, 1921.]

[*To face p.* 134.

That distillation improves the quality of the residual coke is not questioned, and in this respect distillation processes can be usefully introduced.

The possibility of successfully applying brown coal and lignite as a boiler-house fuel has been demonstrated at the Melbourne Electricity Works, Australia, where Morwell brown coal containing 46 % moisture was used in the first experiments on chain grate stokers. Later, the fuel was dried by means of waste heat from the boilers, so that the ultimate moisture content was reduced to below 20 %. The results with raw coal and dried coal, respectively, were as follows :—

	Raw Coal. 50 % Moisture.	Dried Coal. Under 20 % Moisture.
Fuel per hour (lb.)	2997	8000
Furnace temperature	1700° F.	2100° F.
Exit temperature	557° F.	599° F.
Carbon dioxide	10·3 %	13·5 %
,, monoxide	1·7 %	0·33%
Water evaporated (lb. per hour)	6550	20,200

It is contemplated that a pulverised fuel plant will be installed at these works at a later date, when the results given above with stokers should be greatly improved upon.

The use of this fuel in pulverised form would mean a higher CO_2 content in the waste gases, a lower exit temperature and considerably increased steaming rate of boilers.

The Fixation of Gas from Pulverised Coal.

Great interest has recently been shown in America in the question of making gas from pulverised fuel. It has been found possible to subject waste anthracite coal containing up to 50 % of inert material to gasification in producers, but no degree of practical success has yet been recorded. If such waste coal were pulverised, or preferably washed or otherwise treated to remove much of the ash, and then pulverised, it should be possible to gasify the fuel in this form. The progress made in this direction is outlined in the following notes.

In producers of the ordinary type there comes a limit to the rate of gas produced, owing to the excessive temperature attained in the producer by reason of the high pressure necessary for the penetration of the heat into the mass of fuel and clinker.

Marconnet used a design of gas producer retort into which pulverised fuel was fed at so high a rate that the ash introduced with the pulverised coal was fused, and was run off in liquid form. In these experiments 100 to 160 lb. of coal were treated per hour per sq. ft. of section of producer.

Benner and Lewis Processes.

Professor Vivian B. Lewes carried out a series of experiments on these lines in England and filed his patent for the process in 1913 (Brit. Pat. No. 9988). The

illustration, Fig. 17, has been taken from his specification, and is of interest in that it records the contention of an eminent scientist that gas from the complete or partial carbonisation of pulverised coal should be a subject for investigation.

Following upon these earlier experiments and suggestions, Benner in America has advanced the process considerably further towards practical success. An illustration of the producer under the Benner patents is shown in Fig. 18, and the following description supplied by the Fuller Engineering Co. refers to this generator.

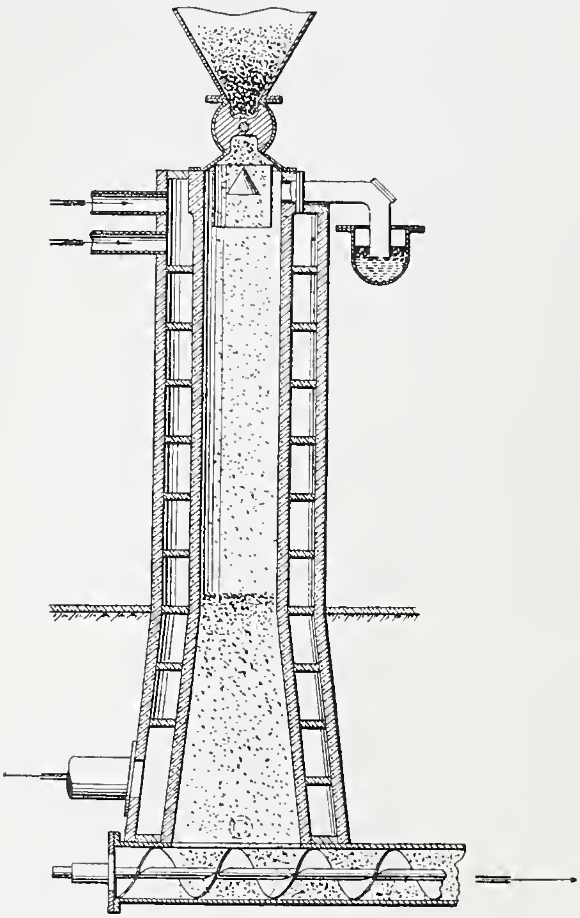


Fig. 17.—" Lewes " Pulverised Coal Gas Producer. (*Prof. Lewes' Patents.*)

A is the generator. B designates the space within the generator above the fuel bed. C indicates the fuel bed, D the grate bars, and E the ash pit. H is the passage way out of the generator through which the blast gases pass through the valve J into the steam boiler K, and also through which the generated gas passes. The generated gas may be by-passed around the boiler through the conduits O, and valve P, thence into the water seal M, scrubber N and so on. F is the air inlet where the blast air is admitted for blowing up the bed to the proper temperature. G is the auxiliary blast inlet wherein air is admitted above the fuel bed during the blast period to permit the blast gases to burn within the generator, thereby heating up the walls to the desired degree of temperature. The top of the generator is heavily bricked to minimise the loss of heat by radiation. The pulverised coal is fed into the generator through the passages RR. The fuel is contained in the bin S and admitted to the seal chamber T by operating the slide valve V, and from T into U by operating the slide valve W. The use of two valves serves the purpose of maintaining a seal between the bin and the discharge chamber U, this being of the requisite volume to contain pulverised coal for one cycle. The valve X is intended to prevent hot gases getting back from the generator into the chamber U. The coal is injected by compressed gas, which is admitted in puffs from a reservoir (not shown) by means of a small mechanically operated valve (not shown) through Y into U. The puffs of gas carrying coal-dust pass out through Z, X and R into the generator. This method has proved susceptible of accurate adjustment and has shown freedom from clogging. TT indicates the cover plate of the generator. Q is a safety cover on

the outlet to relieve any excess gas pressure. NN and MM offer means for burning the gas after it leaves the generator, if so desired. XX and ZZ are the steam line and valve from the boiler to the generator whereby steam is supplied to the bed to form water gas.

The operation is as follows :—

Air is forced through the hot fuel until the temperature of the retort is raised to the requisite degree, when auxiliary air is admitted above the fuel bed, causing the CO gas generated to burn within the top of the generator so as to heat the

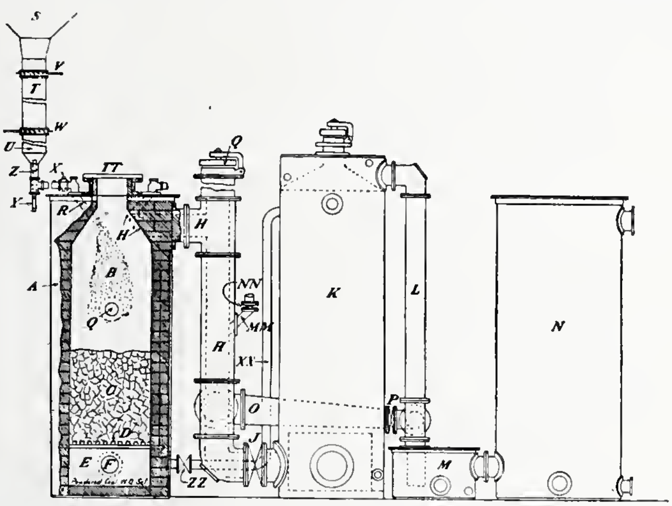


FIG. 18.—Pulverised Coal Gas Producer Plant. (*Benner Patents.*)

walls. When the fuel and the walls of the retort have been brought to a high temperature all air is shut off and steam is admitted below the grate. The steam passing up through the fuel bed generates water gas. The steam flow is then set to a very slow rate and the pulverised bituminous coal injected in puffs forming fuel clouds in the generator. The coal in its finally sub-divided state gives off its volatile constituents almost instantly under the influence of the very hot walls, and forms particles of coke which coagulate sufficiently to fall by gravity on to the fuel bed, notwithstanding the upward current of gas leaving the generator. The carbonised fuel and ash form the subsequent fuel bed for the production of water gas, and so the cycle is recommenced.

CHAPTER VIII

COMPLETE MILL-HOUSE PLANTS FOR THE PRODUCTION OF PULVERISED COAL

Description and Specification of Complete Plant—General Outlay Arrangements—Buildings and Masonry—Individual Items in Complete Plant—Rotary Coal Dryers and the Drying of Coal—The Drying of Brown Coal—Stationary or Static Coal Dryers.

(See Chapter IX for special notes on pulverising coal and description of standard mills therefor)

It is not intended to give an extensive review of the many items of machinery that go to make up complete plants advocated by makers of the numerous different types of machines and apparatus embraced in the general term of "systems." Some of the well-known designs of coal dryers, mills, and other portions of plant are illustrated purely for the purpose of presenting to the reader a typical picture of that portion of the equipment referred to in the description of standard apparatus. (See above note *re* Pulverising Mills.)

It is admitted that much of the information given in this chapter has been based upon trade literature, or has been supplied at the author's request by makers of machinery, for it would not be possible otherwise to describe the salient features of the wide assortment of equipment that has resulted from the exhaustive work of designers and construction engineers in many countries.

There are doubtless many well-known and efficient machines and other plant items of which no mention is made. To do so would unduly extend the pages of this section, and the author hopes that it will be found that the subject as a whole has been fairly and sufficiently explained.

Description and Specification of Complete Plant. (See Folding Plates B and C.)

A complete mill-house plant generally consists of the apparatus and machinery described below, and a typical building for a small complete plant is shown in Fig. 19.

Raw coal storage should be as much under cover as possible. An overhead travelling crane, or a swing jib crane with coal grab, is used to transfer the coal from storage to the mill-house track hopper. When storage hoppers are of large capacity, extending some way alongside or under the railway track belt, conveyors, or other means of collecting coal from any one of several discharge gates fitted to the bottom of a long run of storage track hoppers, must be provided for delivering the raw coal to the preliminary crushers.

Coal delivered by rail truck and dumped into these concrete track hoppers passes

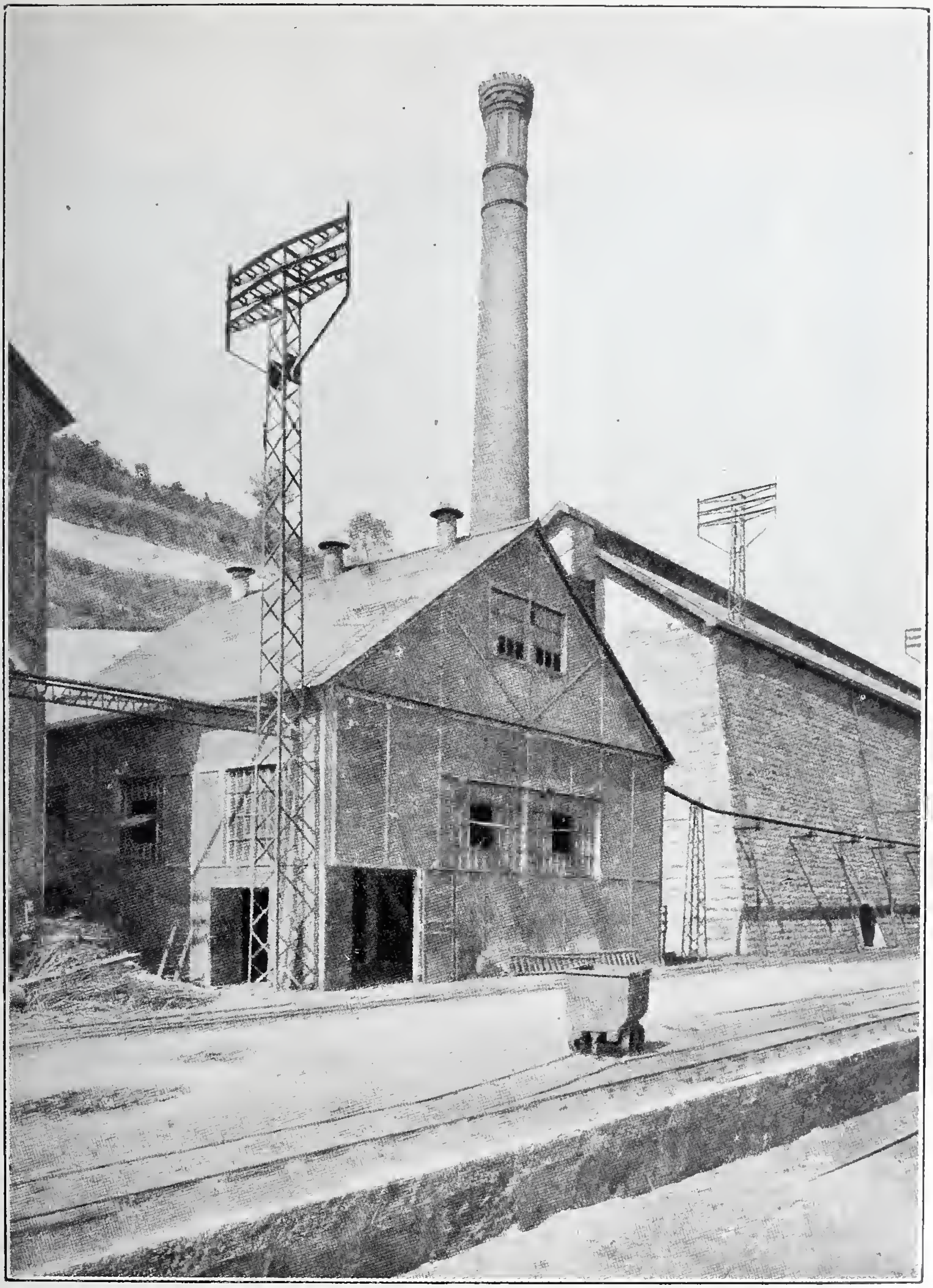


FIG. 19.—BUILDING OF SMALL COMPLETE BERGMAN PULVERISED COAL PLANT, SHOWING FUEL DELIVERY PIPES IN EACH DIRECTION.

L. H. Bergman.] [*American Industrial Engineering Co.*

[*To face p.* 138.

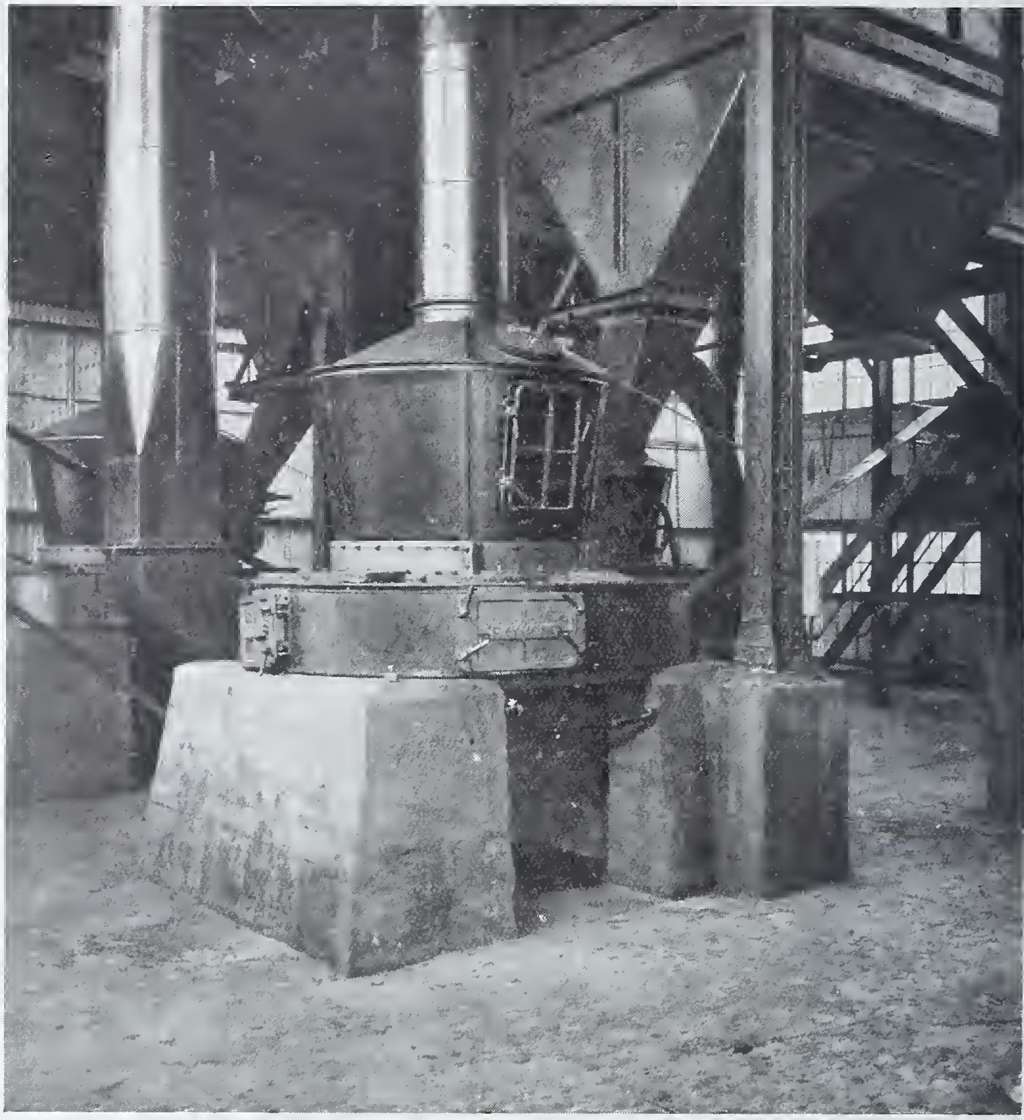


Fig. 20.—Raymond Air Separator Pulveriser Mill, showing enclosed Casing of Mill, Fuel Extractor Pipe (central) and Return Air Pipe (left side).

Raymond Brothers Impact Pulveriser Co.] [*Quigley Fuel Systems, Inc.*

through a gridiron, or covering of bars over the hopper; this open bar grating is called a "grizzley." Any large lumps that will not pass through the 6 in. or so square holes must be broken with a hammer. The supply of coal then contains no lumps above 6 in. cube. The coal falling through the "grizzley" is usually caught by an inclined bar screen, the smalls and dust are taken out, and the lump is collected for crushing down to below 3 in. cube.

In addition to the convenience of handling coal crushed to about this size, it is an easier matter to evaporate the moisture from well-broken and well-mixed coal. Prior to the crushing of the coal, this should pass under an electro-magnet of the crane type suspended close above the surface of the coal as it travels on a band conveyor to the crusher. The magnet will remove any heavy pieces of iron.

The coal, after being crushed, is passed to the crushed coal elevator, of the chain and bucket type, for delivery to the bunker above the dryer.

Crushed coal bunkers are made of iron or ferro-concrete, and are preferably closed at the top to prevent the dust from escaping into the building.

Coal to be dried is stored in bins holding 20, 50, 100 or 250 tons and upwards, depending on the quantity of coal used per day. A few days' supply of crushed coal can be held in the storage bins without fear of spontaneous combustion. As a rule there is constant usage of this fuel, so that coal held in stock does not remain for many days without change of position.

Certain dryers are of the vertical stationary type, direct or indirect, fired or heated by waste gases from furnaces or boilers. The type now coming into general use for power-house plants, and with which good results have been obtained, are referred to at pp. 163 and 275. Coal dryers are usually of the rotary cylindrical type, with furnace hand fired, stoker fired, or pulverised-coal fired, and can be divided into four main classes :—

(*a*) Dryers designed so that the hot gases pass into the dryer and come in direct contact with the coal. This practice is seldom to be recommended, owing to loss resulting from distillation of volatile constituents.

(*b*) Dryers designed so that the hot gases pass right through a central tube in the dryer to the far end and then return into contact with the coal.

(*c*) Dryers arranged so that a division of the hot gases takes place, a small portion finding its way into the dryer in contact with the fuel, the bulk of the gases heating the exterior of the dryer shell before entering the dryer.

(*d*) Dryers designed so that furnace gases envelop the exterior of the dryer shell, none passing into the dryer until the temperature of the gases has been reduced to the safe point.

Coal bunkers are arranged to feed into more than one dryer through angle or breeches chutes, where a number of dryers are installed. Dry coal is collected from the dryers and delivered into the dry coal elevator. This is of similar type to the crushed coal elevator, and the corners and joints should be galvanised to render them dust-tight. Delivery from more than one dryer is taken by a screw conveyor arranged in a trench below the floor level, which feeds the dry coal into the boot of the elevator.

A further magnetic separator is made use of at this point. The dry coal as it issues from the top of the elevator is made to fall on to the moving belt of a magnetic separator, so that any small iron fragments, bolts and nuts, etc., are removed.

It is essential to take out the heavy pieces of scrap iron before coal is passed through the crusher, but even more so to remove the smaller pieces of iron from coal before the fuel is fed into the pulverising mills. Mills fitted with screens for controlling the fineness of the product are especially liable to damage from this source. The coal having been crushed and dried, and the iron fragments removed, it is collected in the dry coal bunkers. These can be severally of sufficient capacity for each pulverising mill installed, or one bunker of large capacity can be fitted with branch chutes to the mills. Dry coal bunkers should be made of iron or ferro-concrete, closed in at the top and vented to the atmosphere.

No particular shape is advocated for the dry coal bins, so long as the bottoms have sufficient taper to clear all coal when the outlets are opened.

It is sound practice not to store more than a forty-eight hours' supply of dried coal. Spontaneous combustion will not occur in this time, provided the coal as delivered from the dryer is not so hot that sweating inside the bin will take place. Cool, dry coal, even lignite and peat, can be kept for weeks or even months, under normal conditions.

The terminal temperature of the coal as it leaves the dryer should not be more than 250° F., but latitude in this direction is governed by the nature of the coal, its ash, and its sulphur content.

Fuel should preferably contain as low a percentage of moisture as is possible if fuel is to be carried in storage; only when the pulverised fuel can be burned within a short time of its preparation is it permissible to dispense with drying plant, provided the mills will function satisfactorily at the degree of moisture in the raw coal.

The question of drying coal becomes all the more important in a country where the atmosphere may contain considerable moisture, for pulverised coal will readily absorb water from the air and become sticky and difficult to handle. Coal-dust when moist will coagulate, and the advantage of initial fine pulverisation will be entirely lost, the fuel passing into the furnace in small lumps instead of in intimate mixture with the air supply.

When calculating the capacity of pulverised coal storage bunkers or supply bins, it is usual to assume that ordinary run-of-mine lump coal weighs approximately 40 lb. and pulverised coal 35 lb. per cu. ft. For every ton (2240 lb.) of lump coal an allowance of 56 cu. ft. storage space should be provided, and for pulverised coal 64 cu. ft.

The pulverising mills, as usually found in pulverised coal plants, are either of the air-separation type (Fig. 20), with which is employed an exhauster fan to remove the fine fuel dust from the mill and to deliver the fuel into a cyclone separator fixed above the mill, or of the screen type, from which the product is discharged at or below the floor level. Ball and tube mills with air separation, or used in conjunction with special vibrating screen classifiers, are coming into greater favour.

A combination of ball mills and tube mills is sometimes used. The former reduce the coal to, say, a 40-mesh standard, and the required degree of fineness is

obtained by passing the coarse ground fuel through the tube mill. The combination of ball and tube mills absorbs a somewhat heavy proportion of power for the output obtained, but the plant is less costly than the standard " high-speed " vertical types of mills in which coal can be pulverised to standard fineness in one operation, and in many cases with half the power required per ton of output that is used for the Tandem system of ball and tube mills. These are matters to be considered in conjunction with all the factors, such as nature of fuel, cost of plant, cost of power, capacity per hour, etc.

As a rule the dryers are rated to comply closely with the maximum capacity of the mills in operation. Crushers are generally started up in advance of the pulverising mills, and are run for a short time after the mills are closed down. In this way a sufficient amount of dry coal is available when the mills are again started up. Coal containing about 10% of free moisture can be dried to 1% of moisture during its passage through a rotary dryer at the standard speed of rotation. When fuel contains a heavier percentage of water, the coal can either be passed through the dryer a second time, or the dryer arranged to retain the coal for a longer period by reducing the speed of rotation of the dryer, or again by using a special long dryer in cases where much moisture is always present in the coal supplies.

When screen separator mills are used, the pulverised coal is delivered into the boot of an elevator of the type used for dry coal, with dust-tight joints, and vented to the atmosphere either directly or through a cyclone separator, to catch the dust issuing at this vent.

Should there be more than one mill, the pulverised fuel is discharged into a screw conveyor running in a trench in the floor in front of the mill discharge spouts. The conveyor delivers the fuel into the boot of the elevator.

The Fuller-Kinyon Pump, or the Pulco Pump, can be used in place of elevator and screw conveyor. Either by means of the bucket elevator, or the pressure pumps, the fuel is transferred to the pulverised coal bunkers. These latter are made of steel or ferro-concrete, and are vented to the atmosphere either direct or through a cyclone separator.

Sometimes the pulverised coal elevator is arranged to discharge direct into a screw conveyor leading to an adjacent furnace or boiler-house, in which case the fuel supply is kept in the bins of the furnaces instead of in a bunker at the mill-house. It may be preferable to deliver the pulverised coal into one or more storage bunkers, from which the fuel can be delivered into the " blowing tanks " for conveying to the furnace bins by means of compressed air. Positive pressure fuel pumps referred to above, or screw conveyors, can equally well be employed for conveying the pulverised fuel from the mill-house bunker to the furnace bins.

Bins used for containers of pulverised coal should always be provided with covers and vented to the atmosphere. They should be constructed with two straight vertical sides from top to bottom, the other two sides being sloped inwards at the bottom to form the required taper towards the outlets. The two straight vertical sides in a great measure prevent the fuel from hanging up or bridging.

Individual electric motors, as generally used in America for driving pulveriser mills and the machinery in a coal-pulverising mill-house, are of the enclosed ventilated

type, there being no necessity for totally enclosing even continuous-current commutator motors; always provided that the plant is well designed, proper dust removal apparatus is installed, and adequate attention is given to clean working conditions in the pulverising station. Possibility of explosion due to the temporary sparking at a motor at the commutator igniting a mixture of pulverised fuel and air is then very remote, the atmosphere surrounding the motor having insufficient carbon particles to constitute an explosive mixture.

Electric motors whether of the horizontal or vertical spindle types when used for belt driving are always, and when used for chain driving are generally, fitted with slide rails, the only exception being in the case of small variable speed motors employed for operating the coal feeders through chain and sprocket wheel drives.

When vertical spindle mills are driven by horizontal spindle motors, or from line shafting, it is necessary to introduce special "belt idlers" to effect the twist in the belt from the horizontal to the vertical pulley. Belt idlers are fitted with adjustments for correctly setting the twist in the belt and at the same time taking up the slack.

An illustration of a Fuller Belt Idler is shown in Fig. 21. Fig. 22 shows a series of Fuller Pulveriser Mills driven by vertical spindle motors; and Fig. 23 from line shafting. Fig. 24 shows a series of direct connected horizontal motors driving Fuller Mills through gearing.

A standard specification embracing the various items included in a complete coal-pulverising station is given below. The plant mentioned is that which would be required for a railway locomotive fuel supply installation having an output of say 7 to 8 tons of pulverised coal per hour.

The power stated for all motors is the rated power in each case. This power would be required only on starting up under load, for under normal running conditions the absorption of power is usually about half the rating of the motors specified.

The approximate net and gross shipping weights are given for the information of readers who may wish to estimate the cost of transportation.

SPECIFICATION OF FULLER PULVERISED COAL PLANT FOR EXPERIMENTAL LOCOMOTIVE FUEL SUPPLY DEPOT.

Capacity required 30,000 tons of Pulverised Coal per annum, normal capacity of pulveriser mills say 150 tons per 24 hours (20 working hours).

Coal Mill Machinery.

	Net Weight. lb.	Gross Weight. lb.
1 Standard 27″ × 7′ 4″ Plate Feeder for Raw Coal, with drive from single roll coal crusher to regulate feed to crushing rolls . .	1,000	1,230
1 18″ × 18″ Single Roll Coal Crusher, capacity 8″ lumps, reducing same to 80 % to 90 % passing $1\frac{1}{4}$″ screen at rate of 35 tons per hour	3,200	4,000
Carried forward	4,200	5,230

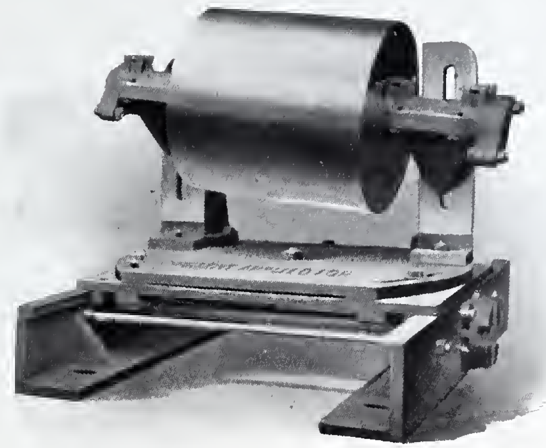


FIG. 21.—FULLER ADJUSTABLE BELT IDLER.

The Fuller Lehigh Co.]

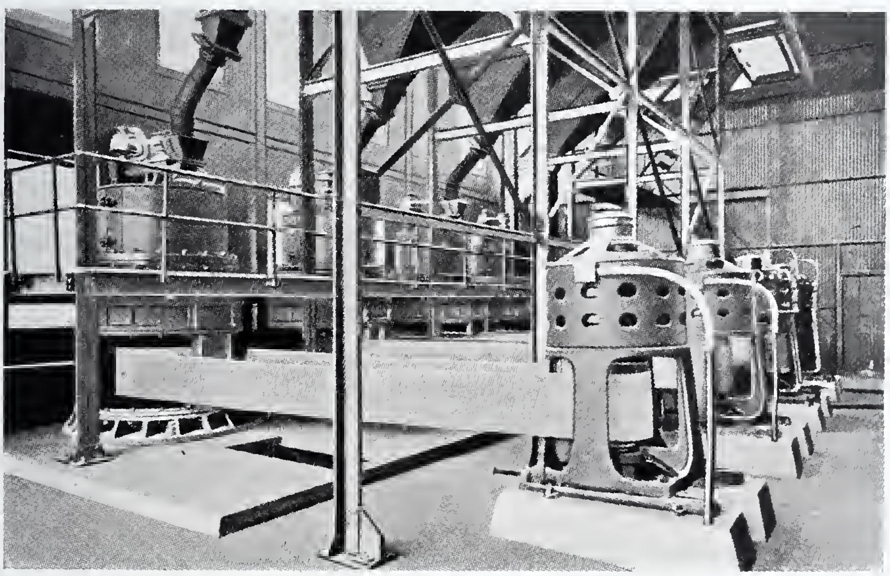


FIG. 22.—FULLER PULVERISER MILLS, SHOWING STANDARD VERTICAL SPINDLE MOTORS.

The Fuller Engineering Co.] [*The Fuller Lehigh Co.*

[*To face p.* 142.

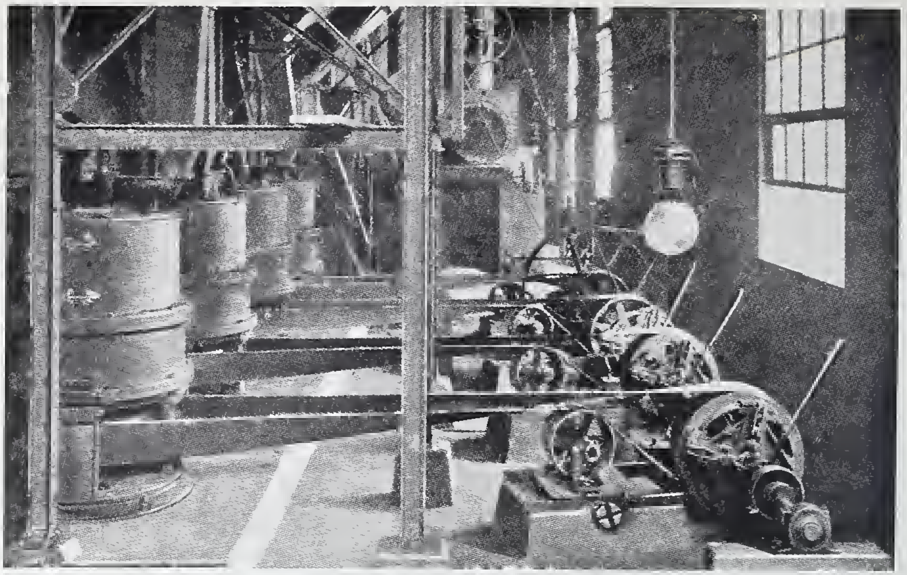


Fig. 23.—Fuller Pulveriser Mills driven from Line Shafting through Friction Clutch Pulleys.

The Fuller Engineering Co.] [*The Fuller Lehigh Co.*

Fig. 24.—Battery of Fuller Pulveriser Mills driven direct through Gearing by A.C. Horizontal Motors.

The Fuller Engineering Co.] [*The Fuller Lehigh Co.*

	Net Weight. lb.	Gross Weight. lb.
Brought forward	4,200	5,230
1 20 h.p. Belt Drive Motor, suitable for driving roll crusher and plate feeder, including starter	1,470	1,600
1 No. 10 Gauge Steel-Encased Continuous Bucket Type elevator 53 ft. centres, having capacity 50 tons crushed coal per hour at 50 lb. per cu. ft., including buckets, chain, head and foot terminals, cast-iron boot, shafting bearings	10,994	12,676
1 7½ h.p. Back-Geared Motor and Starter, dust and oil-proof gear-case, with base and slide rails	1,000	1,350
Gearing consisting of Face-Hardened Sprockets and driving chains for driving elevator and magnetic separator unit	400	500
1 Magnetic Separator Unit for removing tramp iron and heavy fragments from the raw coal supply to crusher	1,500	1,750
1 20-ton Steel-Crushed Coal-Bin and supports over rotary dryer	11,200	12,000
1 12″ × 12″ Cradle Feeder of the reciprocating type for regulating feed of crushed coal to drier	600	820
2 h.p. Back-Geared Motor and Encased Gearing for driving cradle feeder	375	450
Sprocket Wheels and Chain Drive for above	110	150
1 4′ 6″ dia. × 30′ long Rotary Coal Dryer, including driving mechanism (no stack), dryer arranged for pulverised coal firing, capacity of dryer 8 tons per hour based on 10% moisture reduction on coal. (Note.—This dryer requires 18,000 red brick and 5,000 ordinary firebrick.)	55,000	60,000
1 Cyclone Dust Collector for above dryer with piping from exhauster fan	4,610	5,200
1 Rotary Exhauster Fan with water-cooled bearing for extracting the waste gases from dryer	1,500	1,700
1 10 h.p. Horizontal Belted Type Motor for Exhauster	580	1,000
7½ h.p. Back-Geared Motor, and starter, back gearing in case, base and slide rails. No pulley for driving dryer	1,000	1,300
Sprockets and Chain Drive from dryer motor to dryer	400	500
1 5-ton capacity steel Pulverised Coal storage Bin and supports over coal dryer	1,110	1,550
1 ¾ h.p. variable speed 600 to 1,800 R.P.M. Direct Current Back-Geared Motor shunt wound with starter and rheostat controller	450	600
1 Rotary Low-Pressure Fan for supplying air for pulverised coal burner of dryer	250	325
1 3 h.p. Horizontal Belt Type Motor for driving fan, including belt, base and slide rails	250	300
1 Cast Iron Concentric Air Port regulating type burner for dryer.	527	710
126 Ft. of 9″ Screw Conveyor 76 ft. in sand seal trough-balance in concrete trough including all necessary hangers, gudgeons, drive ends, 12 gauge trough, No. 14 gauge cover, for delivering pulverised coal to dryer burner bin, and for returning material from dust collector to dryer discharge elevator	5,350	6,350
1 3 h.p. Back-Geared Motor, including gearing, gear-case, base and slide rails for driving pulverised coal conveyor to dryer burner bin.	500	600
Sprockets and Chain Drives for above screw conveyor	640	800
1 No. 10 Gauge Steel-Encased Continuous Bucket Type Elevator, having capacity 50 tons crushed coal per hour, same characteristics as item No. 4, except 5 ft. shorter	8,940	10,310
1 7½ h.p. Back-Geared Motor, including starter, gearing, dust and oil-proof gear-case, with base and slide rails. No pulley for driving above elevator	1,000	1,300
Face-Hardened Sprockets, and chain drive for driving elevator	600	780
2 20-ton capacity steel Dry Coal Storage Bins over pulverised mills, including supports	22,400	24,000
2 Cast-Iron Bin Gates and Spouts from dry coal bins to pulveriser mills	600	840
2 42″ Fuller Lehigh pulverisers, 54″ pulleys, arranged with vertical shafts and horizontal driving gulleys	62,770	72,350
Carried forward	200,326	227,041

	Net Weight. lb.	Gross Weight. lb.
Brought forward	200,326	227,041
2 75 h.p. Vertical Motors, including starters, pulleys, base and slide rails	11,900	15,000
2 Double Leather Belts for pulveriser mills	220	210
2 Cast-Iron Discharge Spouts from mills	1,360	1,860
20 Ft. 12″ Screw Conveyor, ¼″ flights, mounted on 3″ pipe, including gudgeons, hangers, drive end, and arranged for mounting in concrete floor trough	500	750
1 3 h.p. Back-Geared Motor, including gearing, base and rails for above conveyor	700	850
Face-Hardened Sprockets, and chain drive for above elevator	500	650
1 Steel Conveyor Cover for concrete floor trough	3,200	3,500
1 52″ Dust Collector for pulveriser mill relief connections	2,880	3,312
1 Rotary Type Fan for delivering air through relief connections of mills to dust collector	650	720
1 5 h.p. Belt Drive Motor for fan; and necessary piping to and from fan to dust collector	670	750
1 5 ton Double 1 Beam Hand-Power Travelling Crane over mills for facilitating erection and dismantling of mills	7,400	8,800
1 No. 10 Gauge Centrifugal Discharge Pulverised Coal Elevator, 43 ft. centres, 20 tons per hour, including chain and buckets, head and foot terminals, cast-iron boot, etc.	7,841	8,918
1 10 h.p. Back-Geared Motor, including starter, back gearing, gearing case, base and slide rails, for driving above elevator, and the screw conveyor to pulverised coal storage bins	1,600	1,700
Face-Hardened Sprocket Wheels and chain drives for above elevator and screw conveyor to pulverised coal storage bins	1,100	1,450
30 Ft. of 12″ Sand Seal Type Screw Conveyor, ¼″ flights, on 3″ pipe, including gudgeons, hangers, drive ends, No. 12 gauge trough and No. 14 gauge sand seal cover	1,890	2,350
5 Cast-Iron dust-tight Discharge Gates	400	520
2 22 tons capacity each Pulverised Coal Storage Bins above Locomotive Fuel Supply Truck	22,000	23,000
2 Valves and Leading Spouts for Locomotives, and return connections from locomotive tanks to prevent dusting	1,800	2,200
Various Steel Elevator and Conveyor Chutes	4,000	4,500
Various Steel Runways and Stairs	40,000	44,000
Steel Operator's Platform at pulveriser mills	10,000	10,750
Total weights	320,937	362,831

General Outlay Arrangements.

A general outlay arrangement of a typical pulverised coal plant is shown in Fig. 25. This illustrates a Simon-Carves equipment. Special attention may be drawn to the two systems of conveying pulverised coal as illustrating the choice of methods best suited to the conditions indicated, viz. :—

(*a*) For a number of scattered small furnaces, delivery from the mill-house should be made by the air-pressure system to a receiving tank or tanks near the furnaces, and thereafter a mixture of fuel and air can be taken through main and branch piping to each small furnace.

(*b*) For a compact, straight line, boiler plant under which relatively large quantities of coal are to be burned in combustion chambers of adequate dimensions, the supply to the boiler-house receiving tanks can be made as above (or by screw conveyor) and the pulverised fuel fed to the burners by means of electrically driven feed controllers or mixers.

TYPICAL LAY-OUT OF COAL DUST BURNING PLANT

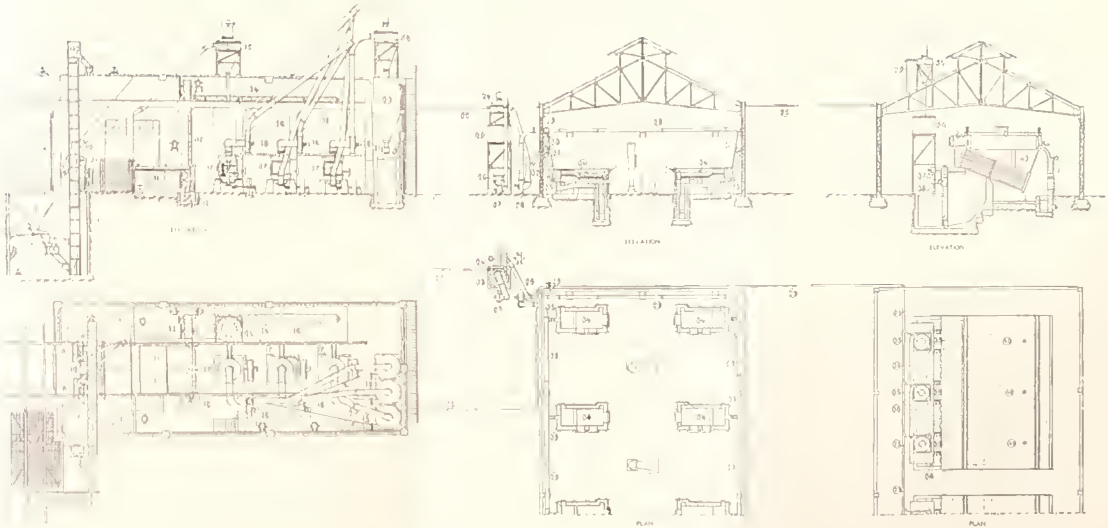


Fig. 25. Simon-Carves System, showing (a) Delivery of Fuel by Air Pressure, (b) Substation and Air Mixture Fuel Supply to Small Furnaces, (c) Individual Fuel Supply Bins at Boilers

Central Pulverising Station.

1. Grating.
2. Unloading Hopper.
3. Automatic Coal Distributor.
4. Coal Crusher.
5. Crushed Coal Elevator.
6. Screw conveying Crushed Coal to Bins.
7. Crushed Coal Bins.
8. Crushed Coal Distributors.
9. Smoke Box of Dryer.
10. Dryer Exhausting Fans.
11. Rotary Dryers.
12. Screw conveying Dry Coal.
13. Dry Coal Elevator.
14. Screw distributing Coal to Reserve Hopper.
15. Cyclone receiving Coal Dust from Hopper.
16. Dry Coal Reserve Hopper.
17. Pulverisers.
18. Pulveriser Fans.
19. Cyclone Separators.
20. Coal Dust Hopper.

Furnace House.

21. Coal Dust Reservoir.
22. Coal Dust Delivery Pipe for Furnaces.
23. Coal Dust Delivery Pipe for Boilers.
24. Cyclone receiving Coal Dust for Furnaces.
25. Coal Dust Hopper for Furnaces.
26. Coal Dust Distributors for Furnaces.
27. Primary Fan.
28. Fan for distribution of Coal Dust.
29. Coal Dust Circulating Pipe.
30. Secondary Air Pipe Line.

Boiler House.

31. Coal Dust Branch Pipes.
32. Branch Pipes conveying Secondary Air.
33. Coal Dust Burners.
34. Furnaces.
35. Cyclones receiving Coal Dust for Boilers.
36. Coal Dust Hoppers for Boilers.
37. Coal Dust Controllers for Boilers.
38. Secondary Air Pipe Line.
39. Coal Dust Burners.
40. Boilers.

[By courtesy of Simon Carves, Ltd.]

[To face pp. 144-5

The Simon-Carves Co. rightly advise that the former system, the air and coal-dust mixture, should be adopted only for furnaces requiring a small amount of coal per hour, up to, say, 224 lb. A small Fuller installation is shown in Fig. 26.

Complete pulverised-coal plants, as supplied by the Grindle Fuel Co., embody several novel and useful features. An outlay arrangement of a Grindle plant is shown in Fig 41. This illustration gives an excellent picture of the course followed by the coal from the point of raw coal delivery to the furnace burners.

The coal is handled by a grab and traveller, then passed through the preliminary crusher and crushed-coal elevator into the feed bin above the dryer. From the special Grindle multi-tubular dryer the coal passes through the mill, from which the pulverised fuel is extracted by air and separated out in the cyclone separator above the pulverised-fuel storage bin. From the latter the pulverised fuel is delivered into the transportation cylinder, to which is attached a compressed air nozzle, by means of which the fuel is forced through the supply pipes to the bins, in this instance a malleable iron melting furnace.

In the Grindle conveying system switch valves, somewhat similar in principle to Quigley valves, are placed at the branches from the main fuel supply pipe, and these, together with the various items comprising this complete plant, are described individually hereafter.

In the opinion of the author, many special and interesting features have been embodied in the Grindle apparatus, which represent in many respects the result of recent American progress in the design of pulverised-coal equipment.

By reason of the reduced length of the Grindle multiple tube dryer, a very compact arrangement can be offered for complete plant having only small output. Diagrams of small-capacity plants for duties specified in the following table are shown in Fig. 42. The overall dimensions of the buildings required for drying and pulverising machinery, based upon a reduction of moisture in coal from 10 % to 1 % and pulverising to standard fineness, can also be ascertained from this table.

Single Grindle Dryer and One Pulverising Mill.					Single Grindle Dryer and Two Pulverising Mills.				
Capacity in Tons per Hour.		Building Dimensions.			Capacity in Tons per Hour.		Building Dimensions.		
Min.	Max.	Width Ft.	Length Ft.	Height Ft.	Min.	Max.	Width Ft.	Length Ft.	Height Ft.
1½	2½	24	40	20	3	5	30	48	20
2	3	30	40	20	4	6	30	56	24
2½	3½	30	48	28	5	7	32	56	30
3	4¼	30	48	28	6	8½	32	56	30
4	5¼	36	56	30	8	10½	36	56	30

A typical central milling plant of the Quigley type is shown in Fig. 43, which illustrates a standard outlay with Raymond air separator roller mill exhausting into cyclone separator situated above the Quigley pulverised-coal blowing tank.

Detail outlay arrangement drawings of larger installations are given in folding plates B and C respectively for air separator and screen separator mill equipments.

Buildings and Masonry.

Buildings for mill-house plants should be constructed of structural steel framework and corrugated-iron roof and sides. It is preferable to build in the panels between stanchions with 9 in. brickwork, for, say, 10 ft. above floor level, and to fill in the ledge on the top of this base wall so that a gradual slope of cement meets the corrugated iron or window-frames above. This will prevent coal-dust from accumulating at this level, and the sloping face can be readily cleared of coal-dust.

The material required for buildings to house plants of various capacities is described in the following table of " quantities," wherein allowance has been made for complete corrugated-iron sheeting for the sides of the building. If brick walling is to be used, adjustment of quantities must be made accordingly.

The figures given below are approximate estimates for buildings that would be required for standard complete Fuller installations. Capital outlay for complete plants, buildings, machinery, etc., and the cost of operating mill-house plant of various daily capacities are given in Chapter X.

BUILDINGS FOR COMPLETE PULVERISED COAL PLANTS, SHOWING " QUANTITIES " FOR STEELWORK AND FOUNDATIONS.

Capacity of Mill Plant: Per Hour / Per 24 Hours	$\frac{1}{2}$ ton 10 tons	$2\frac{1}{2}$ tons 40 tons	4–5 tons 80 tons	8–10 tons 160 tons	12–15 tons 250 tons	16–20 tons 350 tons	20–25 tons 400 tons
No. of Pulverised Mills	1	1	1	2	3	4	5
Tons of structural steel for building framework, stairs, galleries, etc.	25	40	40	60	75	90	100
Squares of corrugated-iron roofing sheets	20	20	20	40	40	55	60
Squares of corrugated-iron sheets for sides of buildings	50	50	50	110	110	125	140
Square feet of ventilating roof louvres	600	750	750	1100	1300	1600	1750
Square feet of windows and doors	1300	1800	1800	2250	2500	3000	3250
Cubic yards of concrete for floor and foundations for building and machinery	50	60	60	75	90	110	115
Cubic yards of excavation work	60	75	75	100	120	135	140

The only other masonry work usually supplied and built by the purchasers of plant is in connection with the brickwork for dryer furnace, totally or partially enclosed dryer cylinder, dust settlement chambers, etc. An idea as to the brickwork required for indirect-fired rotary dryers of the Fuller type, without dust-settling chambers, and for Cummer dryers with dust-settling chambers, with rating of motors in each case, is given below :—

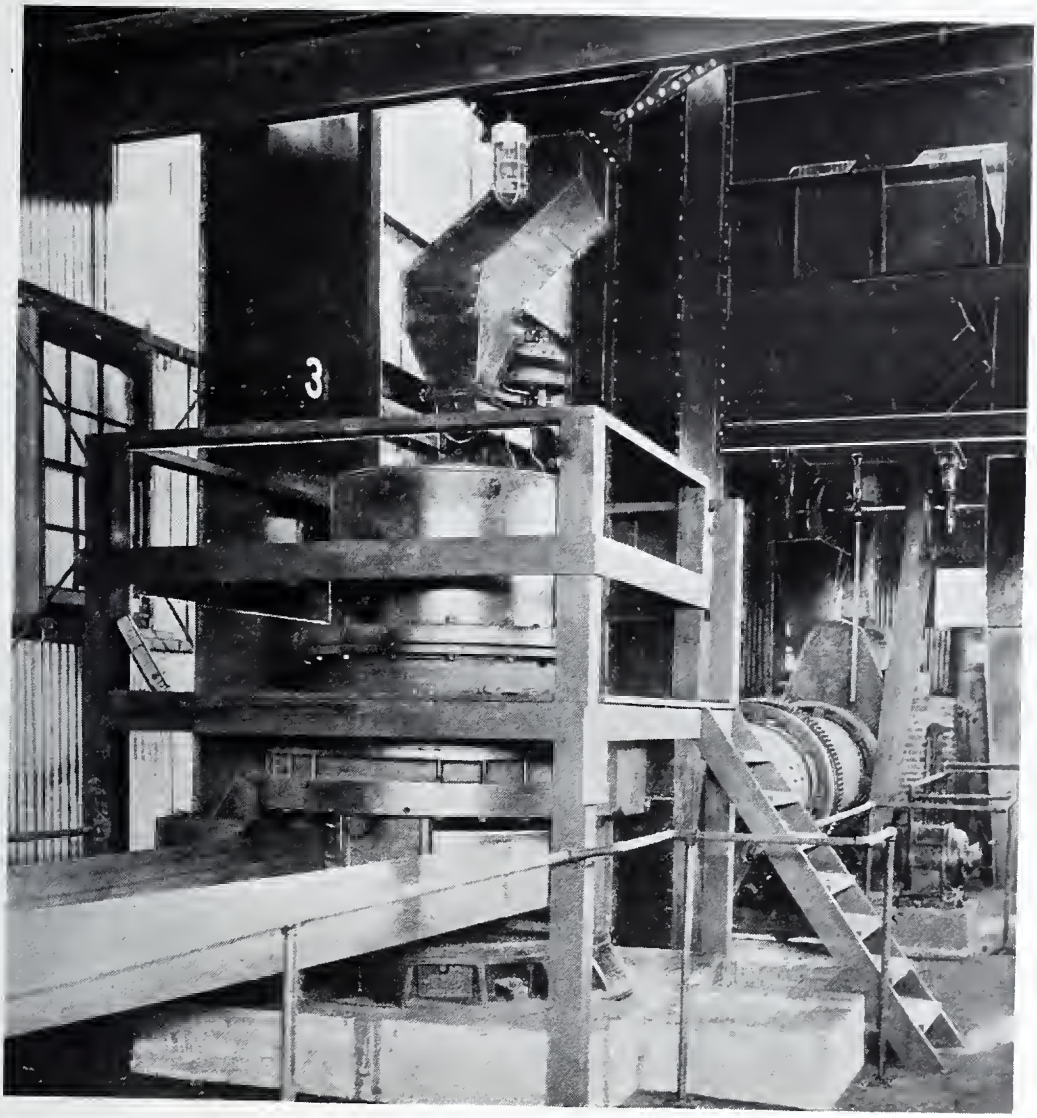


Fig. 26.—Small Fuller Installation, showing Coal Dryer and Pulveriser Mill.

The Fuller Engineering Co.] [*The Fuller Lehigh Co.*

[*To face p.* 146.

Capacity of Fuller Dryer. Crushed Coal per Hour. (10 % Moisture Evaporation.)	Dimensions of Dryer Cylinders. Dia.	Length.	Furnace Common Brick.	Furnace Fire Brick.	Common Brick for Stack Base.	Power of Motors.
2 tons	3′-0″ ×	20′-0″	8,000	4,000	7,500	2½ h.p.
4 ,,	3′-0″ ×	30′-0″	11,000	5,000	7,500	3 ,,
6 ,,	3′-6″ ×	30′-0″	9,000	4,500	7,500	4 ,,
7 ,,	3′-6″ ×	42′-0″	12,000	5,500	7,500	5 ,,
8 ,,	4′-6″ ×	30′-0″	10,000	5,000	12,000	6 ,,
10 ,,	4′-6″ ×	42′-0″	14,000	6,500	12,000	7 ,,
14 ,,	5′-6″ ×	42′-0″	18,000	8,000	12,500	9 ,,
25 ,,	6′-6″ ×	50′-0″	23,000	10,000	14,000	12 ,,

For the same diameter and length of drying cylinders, the capacity of a direct-fired dryer is rather less than that of an indirect-fired dryer; the usual difference ranging from, say, 25% less output for the small dryers to 50% for the largest size mentioned above.

Capacities and Dimensions of Cummer Dryers.

Size.	Capacity per Hour. Coal 10 % Moisture.	Size of Shell.	H.p. of Motor for Dryer, Stoker and Chamber Dust Conveyor.	H.p. of Exhaust Fan Motor.
No. 5	15 tons	66″ × 30′-0″	12	2 to 5
,, 4	12 ,,	60″ × 30′-0″	10	2 ,, 4
,, 3	10 ,,	54″ × 30′-0″	8	1½ ,, 4
,, 2	8 ,,	48″ × 30′-0″	7	1½ ,, 4
,, 1	5 ,,	44″ × 27′-0″	6	1 ,, 3

When coal carries 10% to 15% of moisture, the next size largest dryer is usually advocated.

Approximate Estimate of Bricks and Concrete Required for Cummer Dryers.

	No. 1 Dryer.	No. 2 Dryer.	No. 3 Dryer.	No. 4 Dryer.	No. 5 Dryer.
Red Brick for Dryer	17,500	18,500	23,000	24,000	25,000
Fire Brick for Dryer	3,550	3,900	4,200	4,500	4,900
Red Brick for Dust Room	6,000	7,000	8,000	8,500	9,000
Concrete for Dryer. Cu. Yds.	20	24	29	33½	38
Concrete for Dust Room. Cu. Yds.	4	4½	5	5	5

Individual Items in Complete Plant.

It would serve no useful purpose in connection with the specification of pulverised-coal plant given in the preceding pages to describe in detail all the various small items which go to make up the complete mill-house equipment. The smaller accessories, such as plate or table feeders for supplying regular feed to crushers or pulverisers, are standard for all crushing plants, and require only to be of recognised sound design, simple in action and strong in construction.

Storage or fuel supply bins are briefly referred to in the specification; here, again, it is a question of providing bins of suitable shape to prevent bridging over of pulverised coal, or hanging up of crushed or dried coal on the bottoms of bins having insufficient slope towards the outlets. The strength of plates and supports, and whether bins should be of iron or ferro-concrete, are matters for the engineer to decide, and depend to a certain extent upon local conditions. Climate may also play a part in the ultimate decision as to the type of coal bins to be used. In humid, changeable climates, ferro-concrete construction would no doubt be preferable to roller steel sheet, internal condensation of moisture with ferro-concrete being less than with steel sheet.

Discharge spouts, chutes, valves, gates and other such items are common to all material handling plants, and are not therefore described.

The more important items which are special to pulverised-coal plants, and which require comment, are illustrated and referred to as indicative only of the type of apparatus, in the following pages.

Various types of coal-receiving units have been well portrayed by the Grindle Fuel Equipment Co., whose illustrations and brief descriptions of each design are reproduced from that Company's published literature.

Fig. 27 represents a travelling crane so arranged that, by grab bucket, coal can be taken from the railway wagon and placed on the storage pile, or dumped through bottom discharge doors into the track hopper. The other equipment consists of reciprocating plate feeder and single roll-crusher operated by one constant speed electric motor. The boot of the elevator by which the crushed coal is delivered to storage hopper above the dryer is seen in this view. In the arrangement shown in Fig. 28, the railway wagon is run up a ramp, so that the coal pile is directly over the track hopper. In this case it is assumed that small coal is purchasable—no crusher has been included—and the coal passes from the track hopper to an inclined belt conveyor, over the magnetic separator pulley to the boot of the bucket elevator.

Fig. 29 represents a simple equipment of open inclined bucket elevator to be run continuously as the coal is discharged from the railway wagon, the storage of coal in this case being effected in the coal dryer bin.

Figs. 30 and 31 show in each case a small dump hopper and magnetic separator belt feeder for small installations. For the larger installations, and when coal is dumped over a considerable distance alongside the rail track, a tunnel must be arranged running beneath the coal storage from which the coal can be delivered through openings, controlled by suitable gates, on to a travelling belt collector erected underneath in the tunnel. The coal in this manner can be collected from any one point along the coal pile, and transported by means of the belt conveyor to the crusher or first elevator of the pulveriser plant.

A simple and strong crusher is necessary to break down any large lump of coal to a size suitable for feeding into the pulveriser mills. Feed to mills should usually not contain lumps greater than 2 in. or 3 in. cube.

The well-known Jeffrey crusher is a type generally used for this purpose and is illustrated in Fig. 32. The action employed for crushing is clearly indicated; the main point to be considered in connection with crushers is rigidity, and strength of

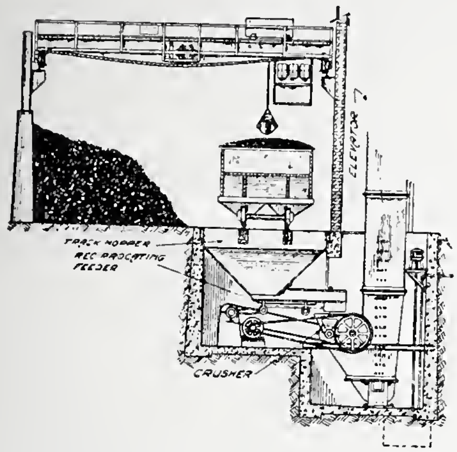


FIG. 27.—Raw Coal Delivery (Lump Coal) Travelling Coal Grab, Track Hopper, Coal Crusher and Elevator. (*Grindle System.*)

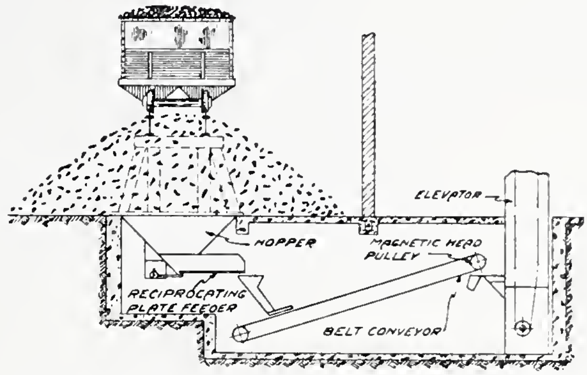


FIG. 28.—Raw Coal Delivery, showing Storage above Track Hopper. (*Grindle System.*)

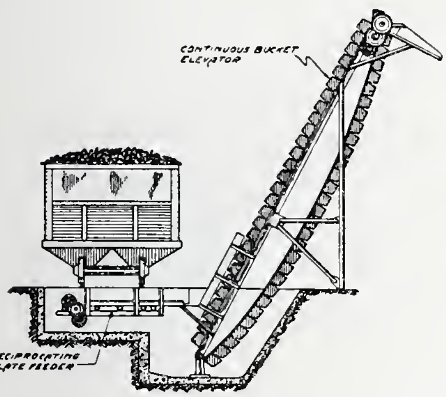


FIG. 29.—Raw Coal Delivery (Small Coal) Track Hopper, Feeder and Continuous Elevator. (*Grindle System.*)

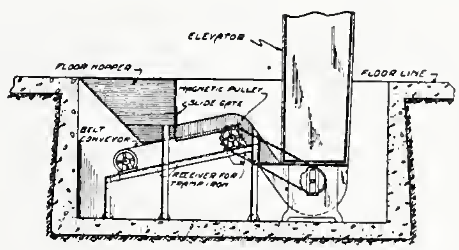


FIG. 30.—Raw Coal Delivery, Small Capacity Coal Hopper, for Small Coal. (*Grindle System.*)

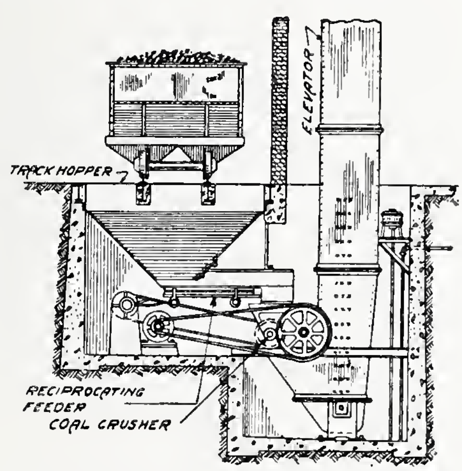


FIG. 31.—Raw Coal Delivery (Lump Coal) Track Hopper, Feeder and Crusher. (*Grindle System.*)

all such working parts or teeth as may be subjected to additional strain should pieces of iron pass into the crusher with the coal. Fig. 33 shows a standard two-roll crusher.

CAPACITIES OF SINGLE-ROLL CRUSHERS.

Capacity in tons per hour to 1″ size.	Size of Crusher. Inches.	Largest Lump in Feed. Inches cube.
15–20	18 × 18	8
30–50	24 × 24	14
50–57	30 × 30	20
75–115	36 × 36	20

As distinct from crushers provided with rollers, another type of crusher frequently adopted is of the spider arm beater design, the gyratory crusher. These are sometimes fitted with two coal inlet openings, each approximately 6″ × 25″, and the spider arms are run at a speed of about 450 r.p.m. through back gearing built up in the housing of the crusher.

For the softer classes of coal these high-speed machines are very suitable, but for large and hard coal single- or double-roll crushers are preferable.

The type of coal crushers recommended by the Fuller Engineering Co. for breaking down lump coal is shown in Fig. 34. This is of the double-roll design; one roll is mounted upon a shaft running in fixed bearings, whilst the shaft of the other roll is carried in floating bearings, held up to the work by powerful springs which can be compressed solid without injury when tramp iron or such uncrushable material is forced through the rolls. The actual roll shells are made in various forms, smooth ribbed, or fitted with teeth, as shown, to suit the class of coal to be crushed. Capacities and powers of these Fuller rolls running at 100 to 120 r.p.m. are as follows for crushing 6 in. cube to 1 in. cube :—

Capacity of Rolls to Crush from 6″ to 1″ product.	Size of Rolls. Length. Dia.	H.p. of Motor.
8 tons per hour	24″ × 12″	5
12 ,, ,, ,,	24″ × 18″	7
16 ,, ,, ,,	24″ × 24″	10
20 ,, ,, ,,	30″ × 24″	20
25 ,, ,, ,,	30″ × 18″	15
50 ,, ,, ,,	36″ × 18″	20
65 ,, ,, ,,	36″ × 24″	30

For removal of heavy pieces of iron frequently found in the raw coal a crane type magnetic separator, as shown in Fig. 35, can be placed over the chute by which the coal is fed into the crusher.

For dealing with small iron or steel pieces such as bolts, nuts, nails and odd fragments, a belt type magnetic separator is usually provided at some point after

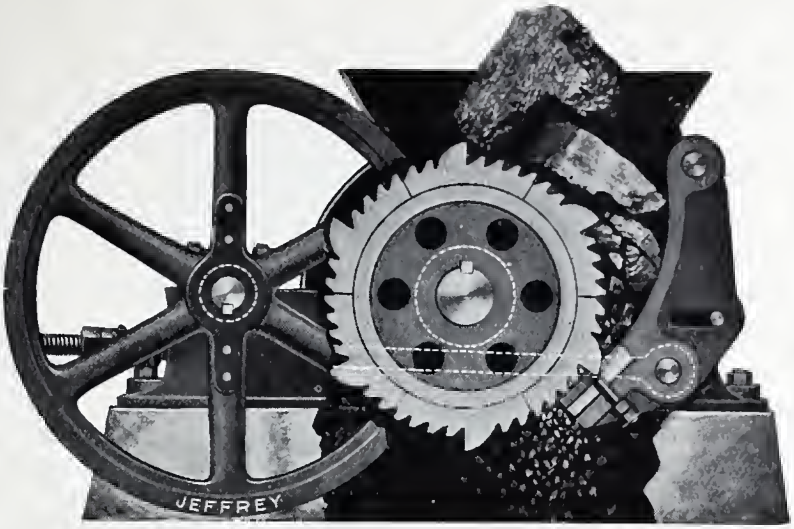


Fig. 32.—Jeffrey Coal Crusher.

Jeffrey Manufacturing Co.]

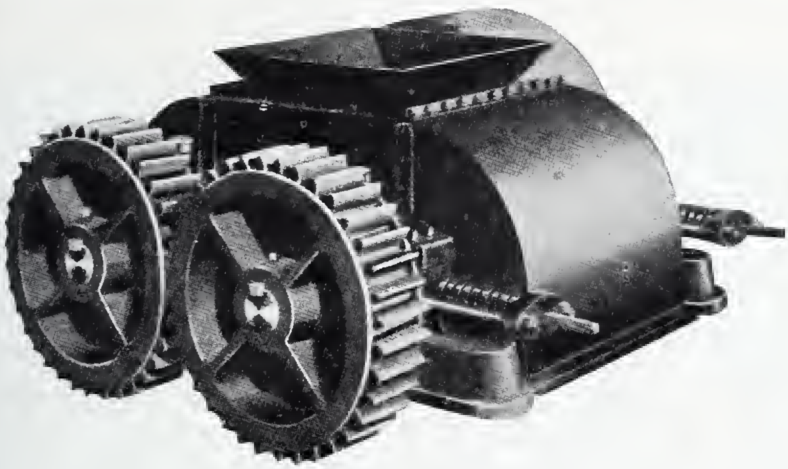


Fig. 33.—Two-Roll Coal Crusher.

The Quigley Fuel Systems, Inc.]

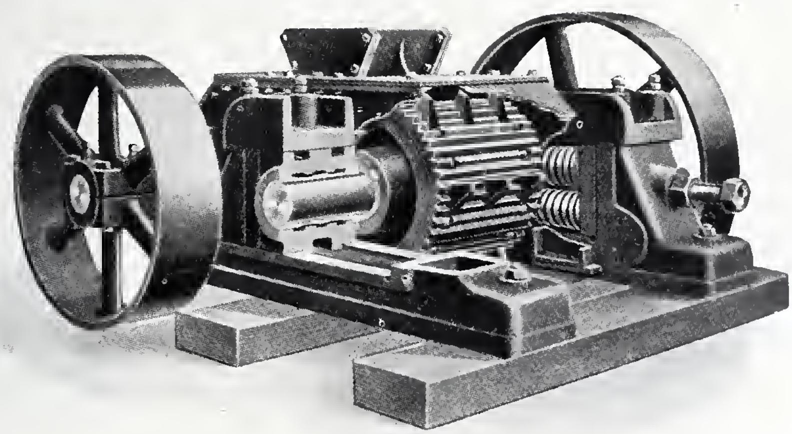


Fig. 34.—Fuller Lehigh Coal Crusher.

The Fuller Engineering Co.] [*The Fuller Lehigh Co.*

[*To face p.* 150.

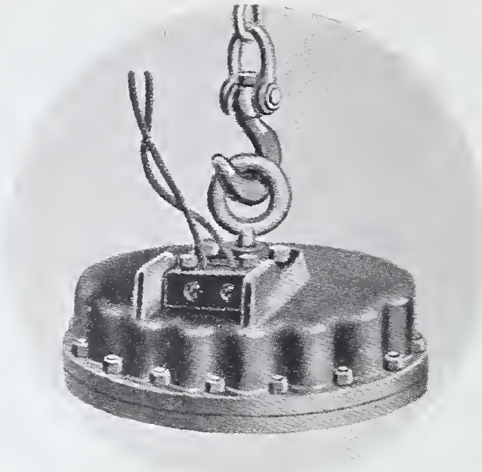


FIG. 35.—CRANE TYPE MAGNETIC SEPARATOR FOR HEAVY IRON.

The Fuller Lehigh Co.]

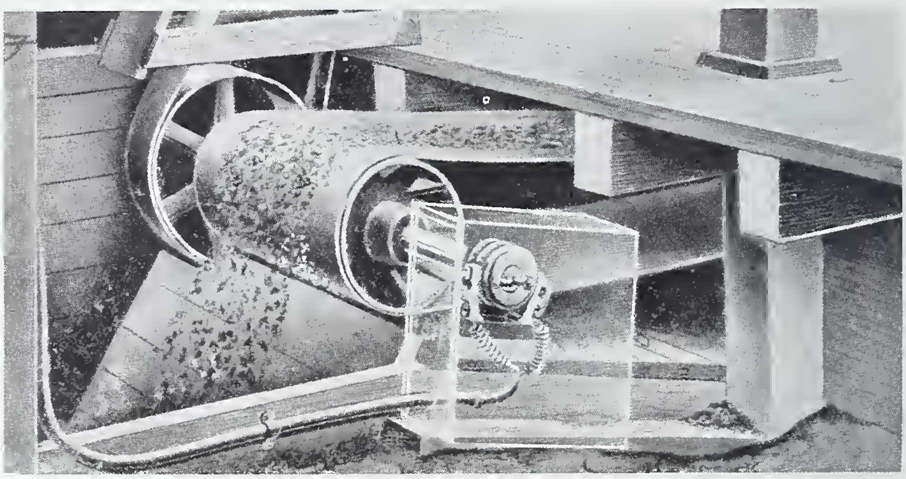


FIG. 36.—MAGNETIC BELT PULLEY SEPARATOR.

The Fuller Lehigh Co.]

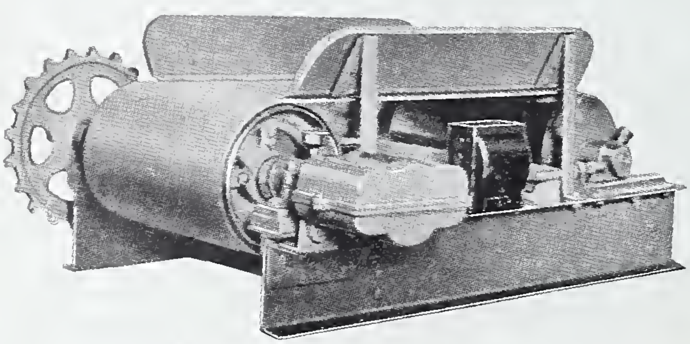


FIG. 37.—MAGNETIC BELT PULLEY SEPARATOR (GRINDLE SYSTEM).

Grindle Fuel Equipment Co.]

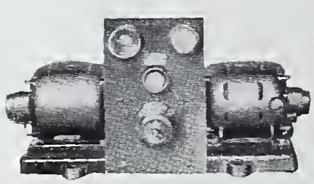


FIG. 38.—MOTOR GENERATOR SET FOR CONTINUOUS CURRENT SUPPLY.

Grindle Fuel Equipment Co.]

the dryer, preferably at the discharge end of the dried coal elevator, the coal passing over the belt to the dry coal storage bin.

Magnetic separators of the usual belt type are illustrated in Figs. 36 and 37 and capacities are given below for various sizes of machines.

Coal Passing per Hour. Tons.	Size of Pulleys. Inches.	Minimum Centres. Feet.	Watts absorbed per Hour.
2	12 × 14	3	274
5	12 × 16	3	616
10	12 × 18	3	616
20	12 × 30	3	968
50	15 × 36	3	1936
75	18 × 36	4	2464

It is essential to apply continuous current to magnetic separators, and when a continuous current supply is unavailable, a small motor generator set must be installed. This is also often required to supply continuous current to the variable speed motors attached to pulverised-coal feeders. A small motor generator set for this purpose is shown in Fig. 38.

The steel elevators, Fig. 40, used in connection with pulverised-coal plants do not differ materially for the three purposes for which these are used, viz. :—

(*a*) For crushed coal; (*b*) for dried coal; (*c*) for pulverised coal. They are always of the bucket and chain type, and particular attention must be given to the casing and venting of elevators.

For each purpose elevator casings should be galvanised. For (*b*) and (*c*) uses the corners of casings must be perfectly sealed, and vent pipes should be connected between the tops of the casings and cyclone separators, or led out of the building to the atmosphere.

Fig. 39 shows standard Sturtevant coal elevators, for which the following table gives capacities, speeds and power required.

STURTEVANT STEEL ELEVATORS FOR CRUSHED OR PULVERISED COAL.

Elev. No.	Buckets.	Spacing.	Drive Pulley under 30′ ctrs.	Drive Pulley 30–60′ ctrs.	Drive Shaft R.P.M.	Chain Speed ft. per min.	Cap. in Tons per Hr. at Listed Speed. 40 lb.	50 lb.	90 lb.	H.p. to 30 ft. ctrs. No. 9 Mat.	H.p. to 60 ft. ctrs. No. 90 Mat.	Wt. per ft.
2	6 × 4	16	24 × 4	24 × 6	150	232	4½	5½	10	·7	1·4	60
3	8 × 5	16	24 × 4	24 × 6	150	232	8½	10½	19	1·0	2·0	65
4	10 × 6	16	24 × 6	24 × 6	150	232	16½	20½	37	1·8	3·6	75
5	12 × 7	19	36 × 6	36 × 8	142	274	26½	33	60	3·2	6·4	98
6	14 × 7	19	36 × 6	36 × 8	142	274	31	38	70	3·6	7·2	100
7	18 × 8	18	36 × 6	36 × 8	142	274	56	70	125	6·2	12·4	130
8	18 × 8	20	36 × 6	36 × 8	142	274	50	63	110	6·2	12·4	135

Rotary Coal Dryers and the Drying of Coal.

An excellent example of a coal-drying plant is shown in Fig. 44. This represents an installation of two Ruggles Coles Rotary Coal Dryers, erected in a drying-

room entirely separate from the remainder of the pulverised-coal plant. Recording thermometers used in connection with coal-dryers are of the type shown in Fig. 45.

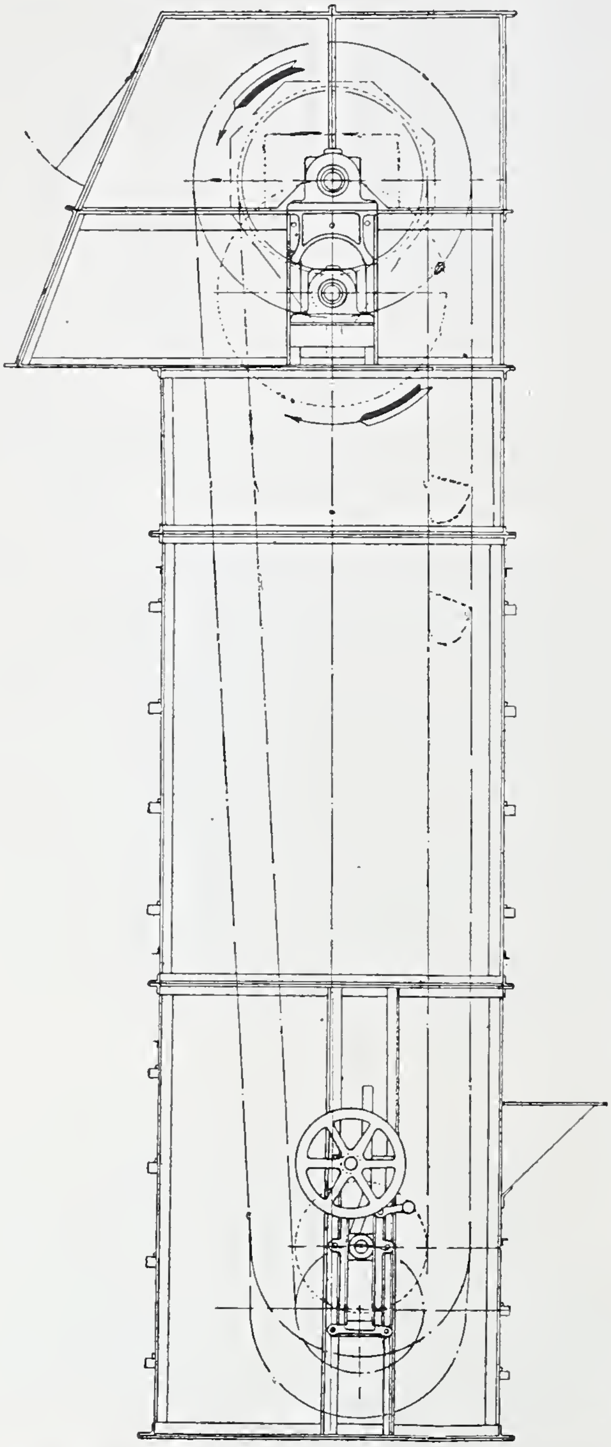


Fig. 39.—Standard Type of Sturtevant Bucket Elevator. (*The Sturtevant Engineering Co., Ltd.*)

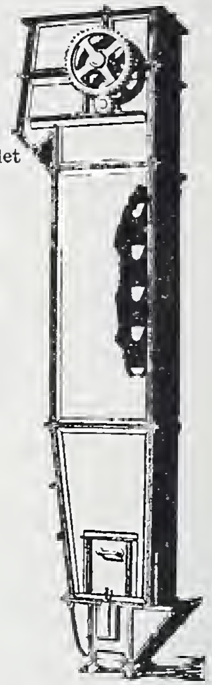


Fig. 40.—Standard Type Bucket Elevator.

The main crushed-coal bunkers will be seen to right and left at the top of the illustration; the fuel to be dried falls through the tapered bottoms of these bunkers into the rectangular screw feeder boxes and thus to the inlet ends of the dryers. The one electric motor in each case operates the feeder mechanism and rotates the dryer.

At the discharge end of each dryer the dried fuel is delivered into the boot of a vertical bucket elevator, and above the central platform can be seen the discharge chutes, through which the fuel falls on to screw conveyors passing out of the building to the dried-coal bunkers in the pulverising house adjoining.

The waste gases and fine coal-dust from the dryers are withdrawn by means

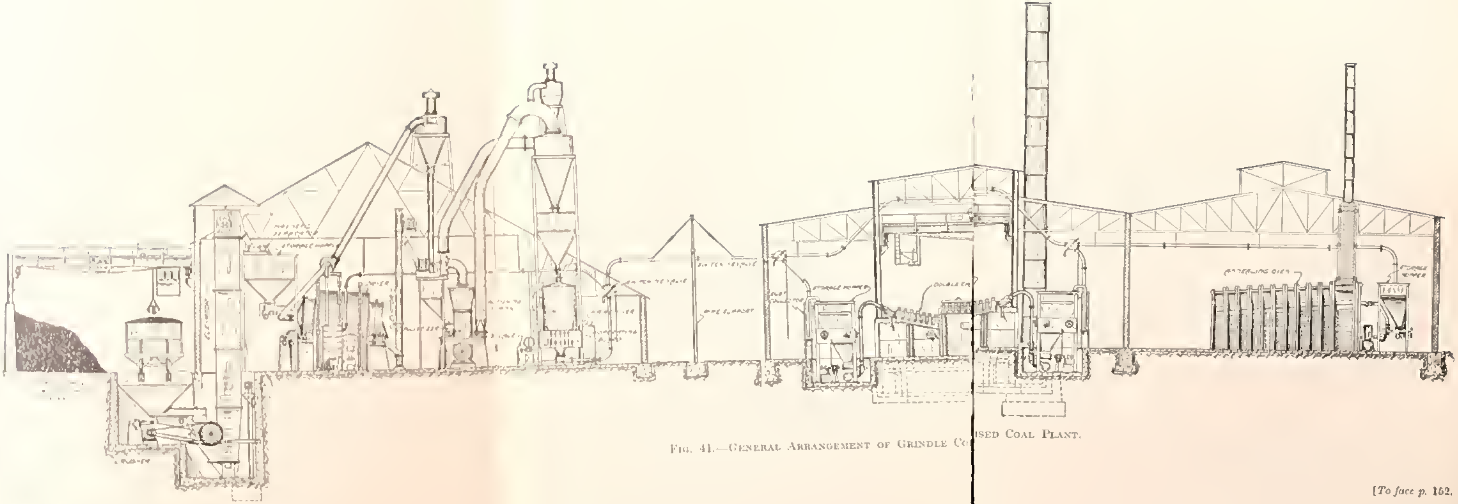


Fig. 41.—General Arrangement of Grindle Co[ ]ised Coal Plant.

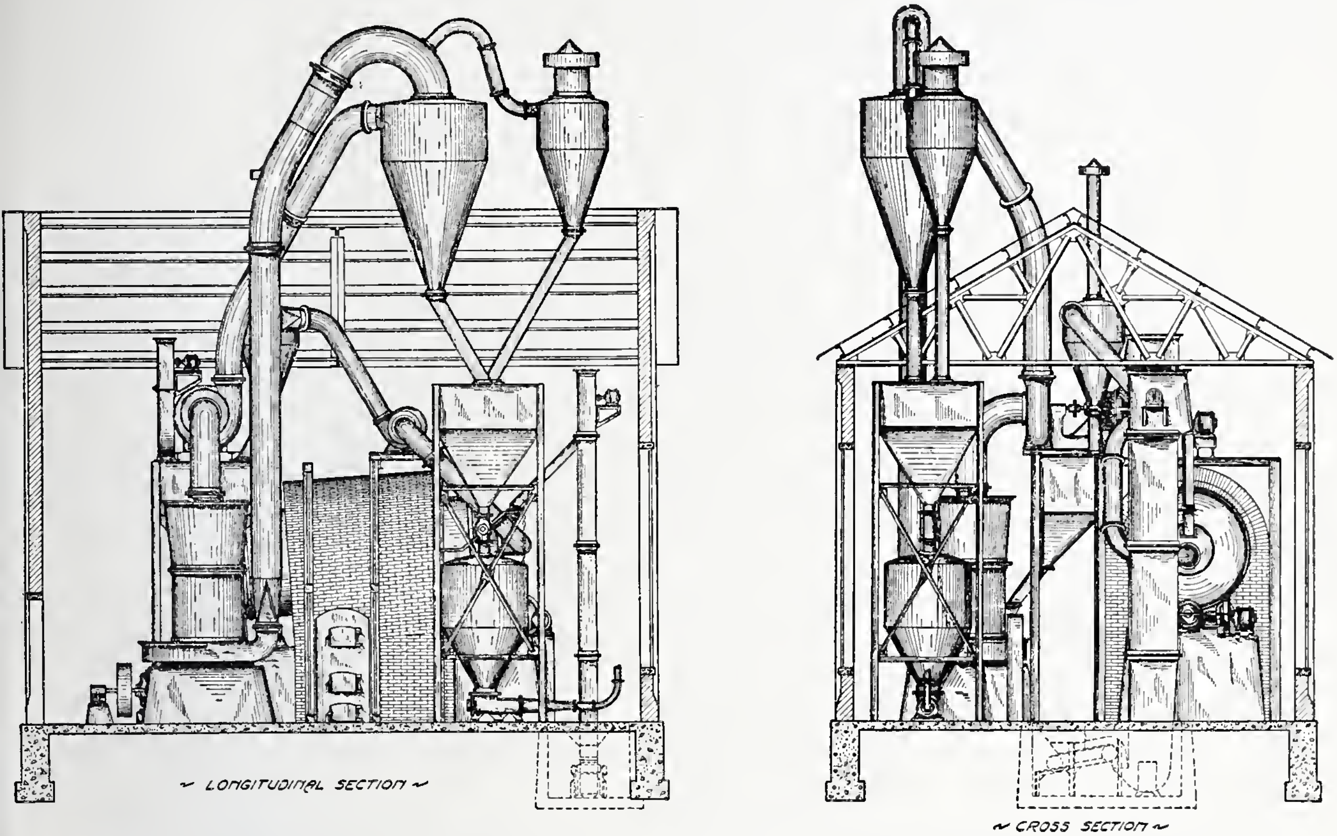
[ ] Fuel Equipment Co.]

[To face p. 152.

1.

rc
tl

of the rotary fans and conveyed through ducts to the cyclone separators, wherein the dust is extracted, collected and delivered through pipes to the screw conveyors which carry away the dried coal.



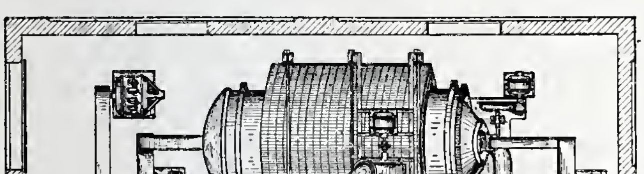


Fig. 42.—Arrangement of Small Complete Grindle Plants. (*Grindle Fuel Equipment Co.*)

A typical exhaust fan unit is shown in Fig. 46, and dust collectors for use with rotary dryers, of the standard Quigley pattern, are of the design shown in Fig. 47.

The efficient drying of fuel prior to pulverisation is one of the cardinal points

to be considered when it is intended to pulverise coal, lignite or peat in large quantities for transportation by any one of the mechanical methods described in Chapter XI, to the bins at the furnaces.

When coal is to be used in smaller bulk, and soon after its reduction to a pulverised state, the question of eliminating as much of the free moisture as may be possible is not of such vital importance.

The proper drying of fuel is of so much importance that further notes on this subject must be given even if repetition of facts already referred to is to a certain extent involved.

Moisture in pulverised fuel has probably been the cause of a great many failures. The many troubles which arise from wet fuel are not always realised, for they are not easily detected without thorough knowledge of the particular characteristics of pulverised fuel. Excessive moisture in pulverised coal may result in a sequence of difficulties, such as packing in storage or supply bins; settlement of fuel in an air and fuel mixture circulating system; solidifying of pulverised coal in blowing tanks; irregularity of feed by controllers; the filling of spaces in screens fitted inside pulverisers, and reduction of flame temperature when wet coal is burned; the jambing of screw conveyors and feeders, resulting in the burning out of motors; uneven firing or "puffing" at the burners; syphon feed troubles.

Many other difficulties can be foreseen; in fact, they are so numerous that it is impossible to mention all that might originate directly or indirectly from insufficient drying of fuel. One of the first axioms of success with pulverised coal is to provide for proper drying, and the larger the plant the more necessary this provision becomes. The drying of coal is usually carried out in rotary dryers. Stationary dryers have recently been used, but as yet this type has not been adopted as standard practice.

A rotary dryer consists of an inclined hollow iron revolving cylinder, inside which are fitted lifting plates or angles fastened to the shell to throw over the coal as it passes through the dryer. The dryer is erected with a slight fall and receives the crushed or slack fuel at the raised end, and discharges the dried coal at the low end. The hot gases from the dryer fire are usually made to pass round the outside of the dryer cylinder, or to travel through a central tube to the far end of the shell, before coming in actual contact with the fuel. The practice of passing the hot gases from the furnace direct into the feed end of the dryer is sometimes adopted, but should be advocated only when circumstances are suitable.

The regulation of dryer temperatures is of considerable importance, and is often overlooked. A sufficient measure of temperatures can be obtained by the use of recording thermometers. As a rule one thermometer (see Fig. 45) is sufficient to indicate the working of the dryer, if the thermometer is inserted at the point where the gases turn back and come in contact with the fuel at the discharge end of the dryer. The recording dial should be placed near the furnace of the dryer, in a position where the operator cannot fail to see it; and, according to the temperature recorded, he can open or close the furnace doors and regulate the fuel supply so as to maintain the final temperature fixed for the drying of the particular grade of fuel to be pulverised. The temperature of furnace gases when brought into contact with

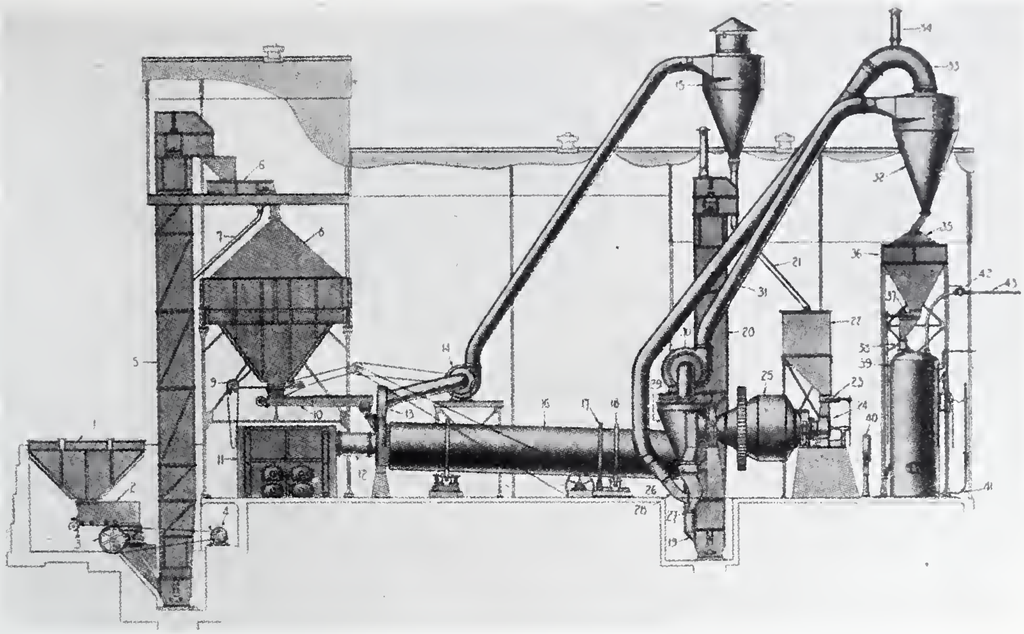


Fig. 43.—Typical Arrangement of Quigley Pulverised Coal Plant, showing Hardinge Ball Mill and Fuel Delivery Pipe.

Quigley Fuel Systems, Inc.]

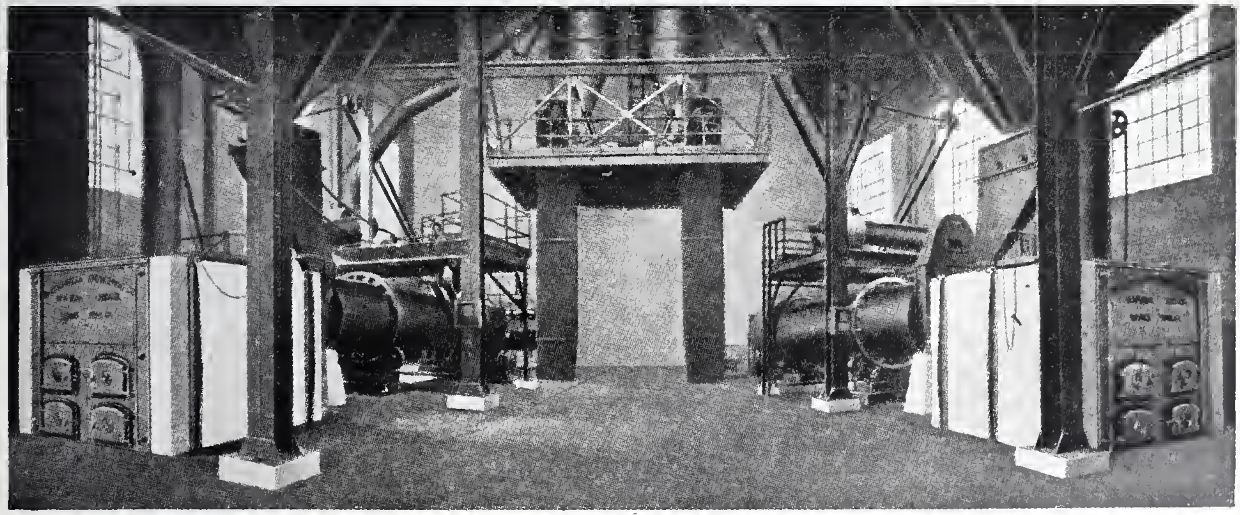


Fig. 44.—View of Two Ruggles-Coles Rotary Coal Dryers, showing Elevators to Screw Conveyor Platform.

Quigley Fuel Systems, Inc.] [*The Hardinge Co.*

[*To face p.* 154.

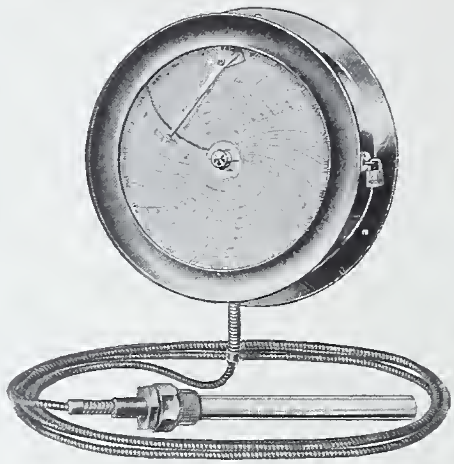


Fig. 45.—Temperature Recorder for use with Rotary Coal Dryers.

The Brown Instrument Co.]

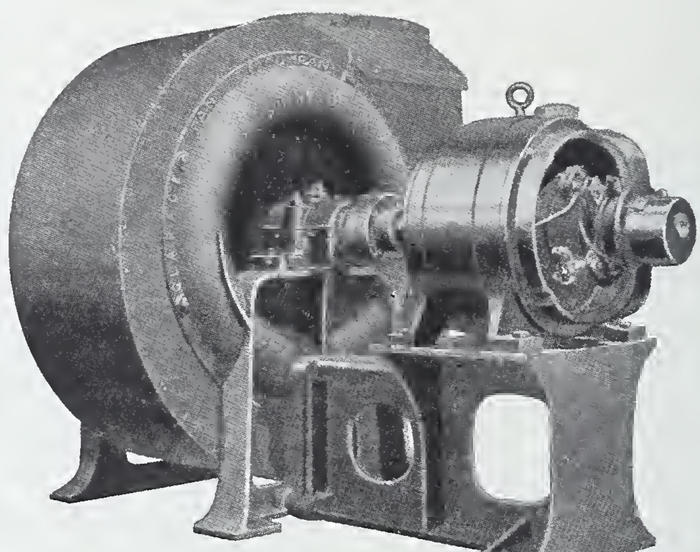


Fig. 46.—Quigley Exhaust Fan for Coal Dryer.

Quigley Fuel Systems, Inc.]

the fuel must be low, because of the generally low ignition temperatures of natural fuel, which are, as a rule, of the following order :—

Dry peat	437° F.
Semi-bituminous coal	620° F.
Bituminous coal	752° F.
Anthracite coal	1292° F.
Coke	1292° F.

Heated air and furnace gases form the medium for the vaporising and removal of moisture. The amount of air required to dry fuel varies with temperature and humidity. The drier the atmospheric air the more moisture it will absorb. The amount of water that air or any other gas will take up increases as the temperature rises, and as the pressure or velocity falls. It is essential that the drying be carried on at as high a temperature as is practicable, also that the air may come into intimate and prolonged contact with the fuel at a temperature sufficiently high to hold, in suspension, all the water that has been taken up from the fuel. The weight of water vapour that can be held in suspension in air heated to various temperatures can be ascertained from reference to Table VIII in Appendix, p. 407.

Coal dryers are usually supplied with exhausting fans to pull the furnace gases through the dryer, and to exhaust the moisture-laden gases to the stack or cyclone dust separator.

The volume of dust given off by dryers has, in some cases, been very objectionable. This may result from running a dryer at a duty above its rated capacity, the velocity of gases passing through the dryer having been unduly increased, in consequence of which an undue proportion of the coal-dust is conveyed through the fan. Too high a temperature may also result in a heavy discharge of dust, for the dust particles are so small that they will remain in suspension in dry air moving at the rate of 50 ft. per minute; whereas, should there be the requisite amount of moisture in the air, the dust may not remain in suspension even when the velocity of gases through a dryer is 175 ft. per minute. Overrunning of the dryer fan, or the overheating of the dryer, often accounts for dust being seen periodically at dryer stacks, while at other moments only steam or a colourless vapour is given off at the stack.

As an example of this intermittent dusting, Coutant cites a case where a 10-ton dryer was in operation. When started up, quantities of dust were produced at the cyclone vent opening, and also a considerable amount of dust was collected in the bin under the cyclone. By means of a pitot tube placed in the pipe leading from the dryer to the fan, and by making connection with a differential draft gauge, the velocity pressure was determined, and the volume of gases passing through the dryer ascertained.

By calculations made for an average temperature of 200° F., the velocity of the gases through the dryer shell was found to be 309 ft. per minute. The velocity of the gases was reduced by slowing down the fan and a second test made. The velocity of the gases had then been reduced to 143 ft. per minute, and all trouble of dusting was overcome.

In this particular instance in Pittsburg, the atmospheric conditions were, temperature 41° F., humidity 80 %. From Table VIII, p. 407, it will be seen that saturated air at 41° F. will carry 0·00043 lb. water vapour per cu. ft., and at 80 % humidity will, therefore, hold 0·00344 lb. per cu. ft. The table also shows that this air and gas when heated to a temperature of 200° F. has a carrying capacity at saturation of 0·03054 lb. per cu. ft. It is, however, impossible to use gases at full saturation point as a vehicle to remove moisture, and it is assumed that a degree of saturation approximately equivalent to the point of dampness, say, 70 % humidity, exists. The gases will then carry 70 % of 0·03054 = 0·02138 lb. per cu. ft. at 200° F.

The volume of dry air at 200° F. required to dry 1 ton (2000 lb.) of fuel containing 10 % moisture (200 lb. of water) under the above conditions would then be approximately 9400 cu. ft. at 200° F. The cross-section of the dryer in question was such that a velocity of gases of 143 ft. per minute through the dryer, as in the second test, was effective in sufficiently drying 16 short tons of coal per hour, the coal containing 10 % moisture, and the temperature at the discharge end of the dryer, where the gases were returned in direct contact with the fuel, was 280° F.

Exhausting fans should always be used in conjunction with coal dryers, and they should always be connected up with cyclone dust separators, into which the dust-laden gases are passed. Provision must also be made for running the dryer furnace under natural draught.

In the cyclone separator, and depending upon the nature of the fuel and conditions referred to above, between 80 lb. and 100 lb. of dust will be recovered from each ton of coal dried per hour, or, roughly, about 5 % of the weight of slack coal containing pieces up to $\frac{5}{8}$ in. size. The quantity of dust recovered from large lump coal which has been crushed to 1 in. or 2 in. cube will, naturally, be less, and should not exceed 3 % of the weight of fuel dried.

The collected dust will usually average a fineness of 60 % to 70 % through 100 mesh, and 55 % to 60 % through 200 mesh. Coal-dust of this description can be fed as fuel to the dryer furnace, and when this method of firing is adopted, such dust can be used for this purpose, otherwise the delivery from the cyclone separator is connected by means of a screw conveyor to the boot of the dry-coal elevator and the recovered dust passed through the pulveriser mill.

As to fuel consumption for the drying operation, some figures are given in a later table for standard Ruggles-Coles dryers (see p. 159). The usual basis taken for hand firing is the evaporation of 6 lb. of water per lb. of 12,000 B.Th.U. coal, and for pulverised-coal firing, either a reduction of 20 % in fuel consumption over hand firing can be made, or an equivalent increase in evaporation to $7\frac{1}{2}$ lb. of water per lb. of coal used.

No ready means have yet been evolved for the determination of moisture in coal as it leaves the dryer or the pulveriser.

Practical data, and regularity of readings as to speed of rotation of the dryer and the temperature records, are the only fixed indications available for the guidance of the operator, but these readings will tell an experienced man whether

FIG. 47.—FUEL SUPPLY CYCLONE SEPARATOR (QUIGLEY SYSTEM).

Quigley Fuel Systems, Inc.]

FIG. 48.—THE BONNOT DIRECT-FIRED ROTARY COAL DRYER.

The Bonnot Co.]

[*To face p.* 156

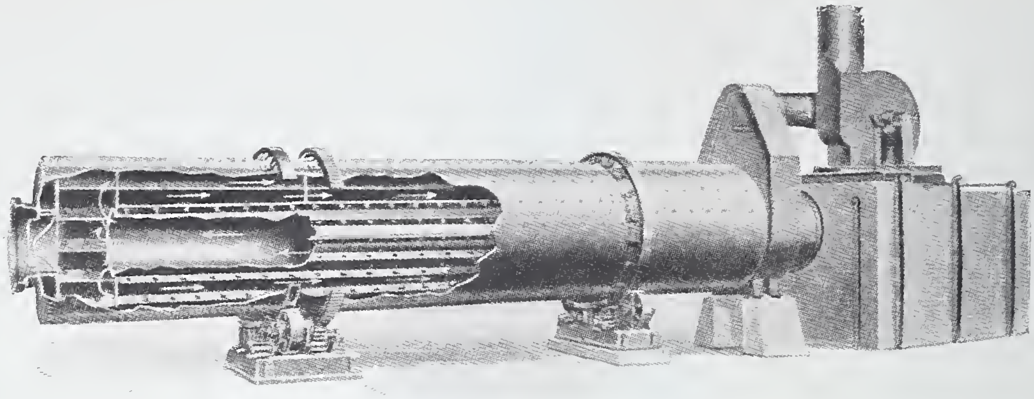


FIG. 49.—THE RUGGLES-COLES ROTARY COAL DRYER.

The Hardinge Co.] *[The Ruggles-Coles Engineering Co.*

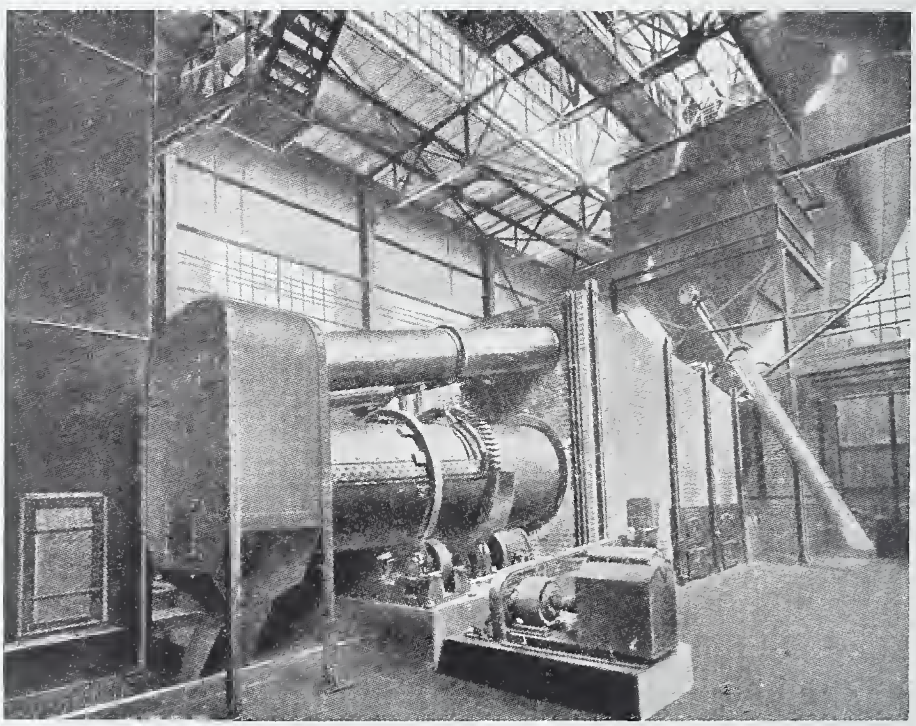


FIG. 50.—FULLER ROTARY COAL DRYER, SHOWING DISCHARGE TO SCREW CONVEYOR OR BUCKET ELEVATOR.

The Fuller Engineering Co.] *[The Fuller Lehigh Co.*

the coal of regular moisture content is being sufficiently dried. When, however, moisture in coal exceeds the normal percentage to any extent, there is no accurate method of determining the moisture in the dried fuel except by taking a sample and drying out the moisture.

In practice, it is necessary for the operator to become so accustomed to the feel of dry coal-dust that he can roughly and with sufficient accuracy determine whether the fuel leaving his dryer is right and does not contain too much moisture. In making this rough test, the lumps of coarse coal should be removed, so as to leave as much fine coal as possible in the hand, and the squeezing of a handful will give to an experienced man a fairly close indication of the moisture it contains by the readiness with which the fuel can be solidified.

Some technical notes on the drying out of moisture in fuel are given at p. 60.

It is an easy matter to dry ordinary classes of coal from crushed lump to fine slack, but the evaporation of water from washery sludge is a much more difficult operation, and special attention must then be given to the design of dryer. A direct fired dryer should never be used for this purpose.

The quantity of moisture evaporated from coal sludge has been determined by actual test taken on a 5 ft. dia. × 50 ft. rotary indirect-fired Fuller Dryer, when the following results were recorded. In this dryer the sludge was treated at the rate of approximately 8 tons per hour, the temperature of coal as discharged being 200° F.

Sample.	Time.	% Moisture as Recd.	Time.	% Moisture Dry.	Temperature of Gases at Discharge End.
A	8.00 a.m.	22·41	8.15 a.m.	5·29	595° F.
B	10.00 a.m.	21·03	10.15 a.m.	5·77	605° F.
C	12.00 noon	20·43	12.15 p.m.	6·05	615° F.
D	2.00 p.m.	20·77	2.15 p.m.	5·94	615° F.
E	4.00 p.m.	21·41	4.15 p.m.	5·06	620° F.
F	6.00 p.m.	20·44	6.15 p.m.	4·94	625° F.
G	8.00 p.m.	21·20	8.15 p.m.	6·24	630° F.
H	10.00 p.m.	20·90	10.15 p.m.	5·90	630° F.
I	12.00 a.m.	22·41	12.15 a.m.	6·33	625° F.
J	2.00 a.m.	21·92	2.15 a.m.	6·87	615° F.
K	4.00 a.m.	20·18	4.15 a.m.	8·26	620° F.
L	6.00 a.m.	20·96	6.15 a.m.	6·29	615° F.
Average		21·17		6·08	618° F.

The Holbeck or Bonnot type of direct-fired dryer, as illustrated in Fig. 48, consists of one single shell, and the hot gases from the furnace pass directly over the fuel and in contact with the fuel from end to end of the cylinder.

The single-shell type of dryer is perhaps more suitable for drying low-volatile coal, such as anthracite. For bituminous coal, lignite, etc., containing higher percentages of volatile matter, some of which must be liberated at relatively low temperatures, the indirect-fired types of dryers should be used. In single-shell dryers the temperature of gases entering the dryer is often excessive, and coal can be actually set on fire at the furnace end.

Another simple type of rotary dryer of the direct-fired type is shown in Fig. 51. This depicts a Sturtevant single-shell dryer, and firing chamber with chimney, and by-pass for use when lighting the furnace, or when the dryer cylinder is stopped with coal therein.

A diagrammatic arrangement of exhaust fan and cyclone separator for extracting

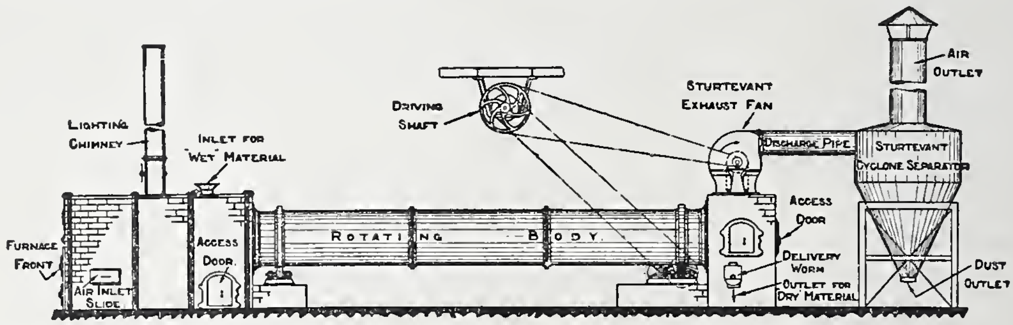


Fig. 51.—Direct Fired Sturtevant Coal Dryer. (*The Sturtevant Engineering Co., Ltd.*)

the dust from the waste gases is indicated. The dry fuel in this case would be collected in the trough of a worm conveyor, and thereby discharged into the boot of the dry-coal elevator, together with the dust collected in the separator. In cases where waste heat is available for complete or initial partial drying, the arrangement shown in Fig. 52 can be adopted.

An example of the indirect-fired type is the Ruggles-Coles dryer, a dryer

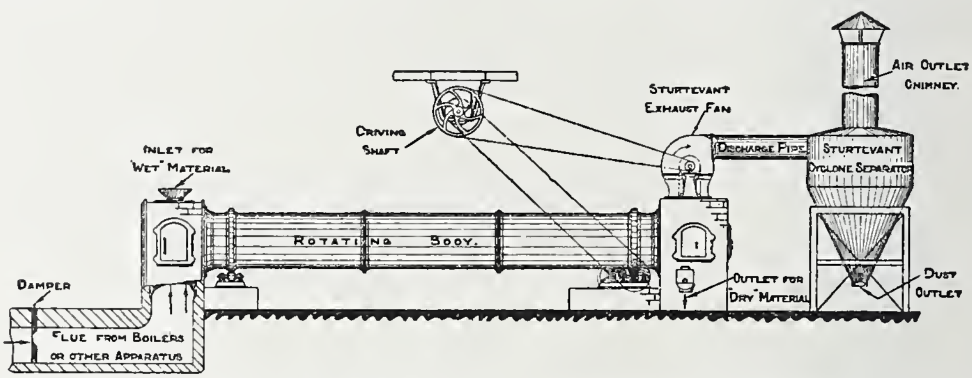


Fig. 52.—Sturtevant Waste Heat Coal Dryer. (*The Sturtevant Engineering Co., Ltd.*)

extensively used in America for drying coal. A " phantom " view of this apparatus is shown in Fig. 49.

In this case the hot gases from the furnace enter the central tube of the dryer and pass through to the housing at the discharge end without coming in contact with the fuel to be dried. The temperature of gases has by that time become sufficiently reduced to permit of their being returned between the centre tube and the dryer shell and in contact with the fuel. An exhaust fan is connected up to the head or feed end of the dryer.

For this type of dryer, the approximate amount of coal burned in relation to

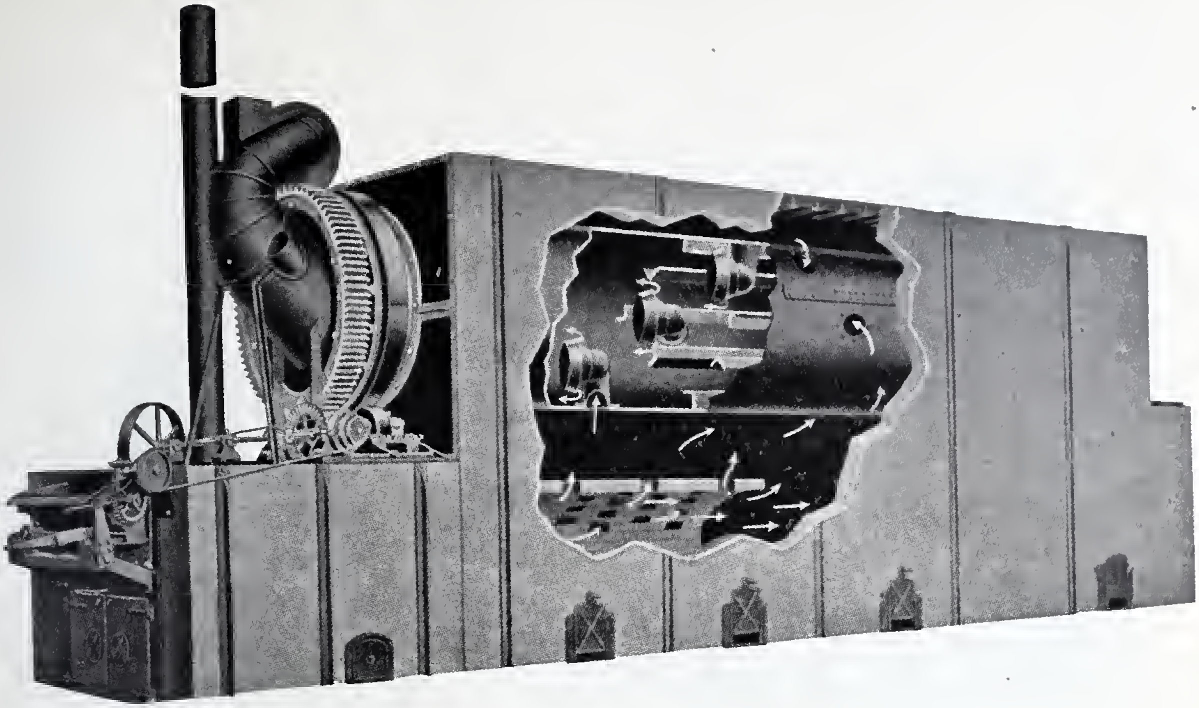


Fig. 53.—The Cummer Rotary Coal Dryer.

The F. D. Cummer and Son Co., Cleveland.]

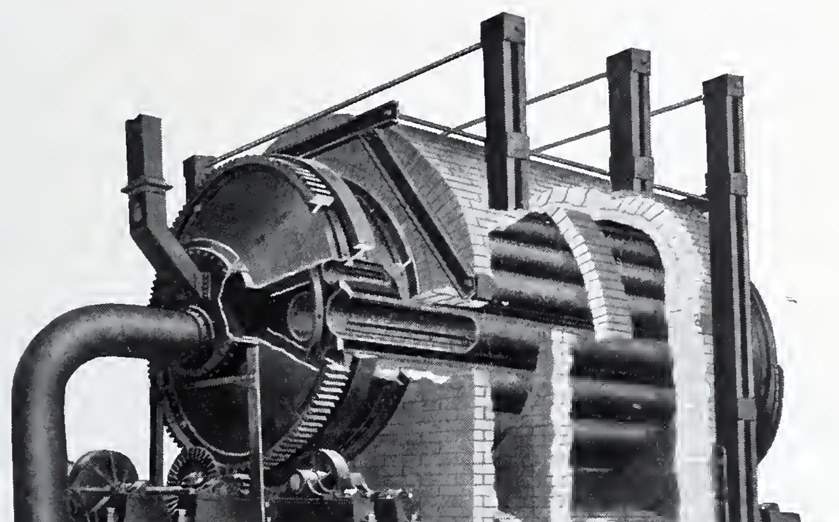


Fig. 54.—Grindle Multiple Tube Rotary Coal Dryer.

The Grindle Fuel Equipment Co.] [*To face p.* 158.

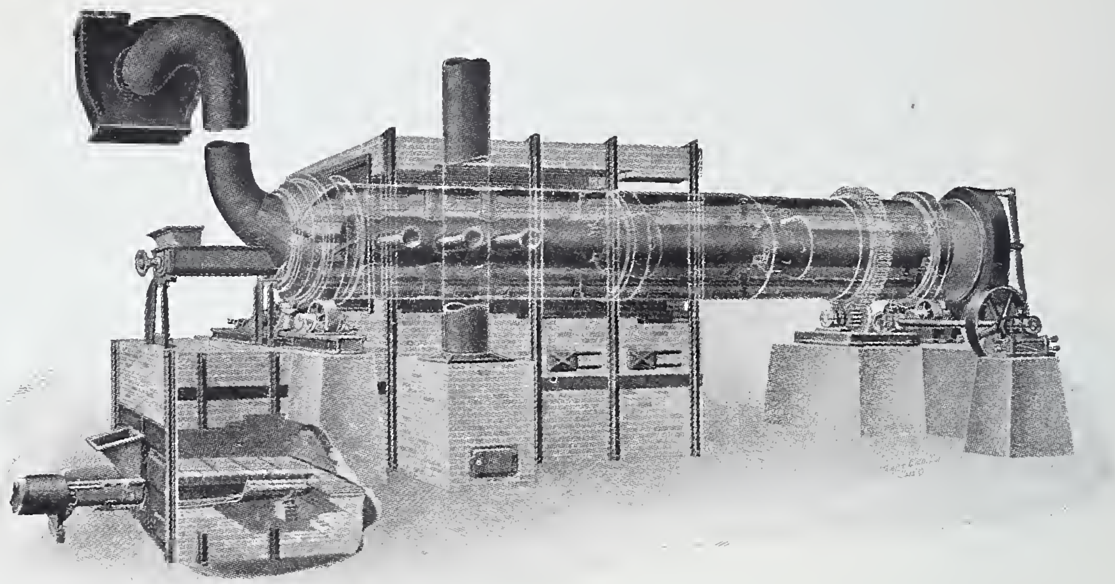


FIG. 55.—BUCKEYE TYPE "A" ROTARY DRYER FOR HIGH MOISTURE COALS, CULM AND SLUDGE.

The Buckeye Dryer Co.]

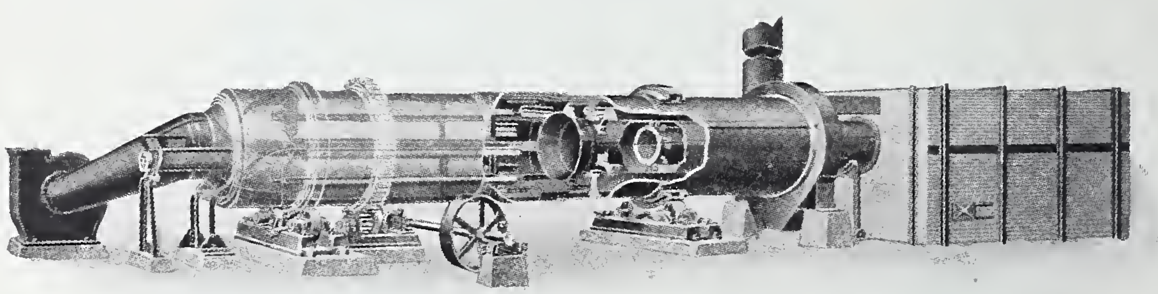


FIG. 56.—BUCKEYE TYPE "B" ROTARY DRYER FOR MODERATE MOISTURE COALS.

The Buckeye Dryer Co.]

the capacity of the dryer, when the original total moisture of various quantities in coal is reduced to 1 %, has been given by Raymond as follows :—

Percentage of Moisture in Coal as received at the Dryer.	Coal (14,000 B.Th.U.) Consumed per Hour for Firing Dryer. (Capacity of Dryer in Tons per Hour.)					
	160 lb.	230 lb.	350 lb.	540 lb.	715 lb.	900 lb.
1	19·5	28·1	43·2	66·8	88·9	113·0
2	15·3	25·1	33·5	51·8	68·9	86·3
3	12·7	18·2	27·5	42·4	56·4	70·6
4	10·7	15·5	23·6	36·4	48·4	60·6
5	9·3	13·3	20·3	31·3	41·6	52·2
6	8·1	11·7	17·7	27·4	36·4	45·7
7	7·2	10·4	15·7	24·1	32·1	40·2
8	6·5	9·4	14·3	22·0	29·3	36·7
9	5·9	8·5	12·8	19·8	26·4	33·0
10	5·4	7·8	11·8	18·4	24·4	30·4
11	5·0	7·1	10·8	16·7	22·2	27·8
12	4·6	6·6	10·0	15·3	20·2	25·2
13	4·2	6·1	9·3	14·4	18·9	24·0
14	3·9	5·7	8·6	13·3	17·7	21·9
15	3·7	5·3	8·0	12·3	16·3	20·2

Another standard type of indirect-fired dryer is the Fuller Dryer, which differs from the Ruggles-Coles and Cummer indirect-fired Dryers in that the heating chamber surrounds a considerable portion of the drying cylinder. In this way the furnace gases first come in contact with the walls of the cylinder on the outside; they are then collected and passed through a conduit to the discharge end of the dryer, and return through the cylinder in direct contact with the coal. This type of dryer is shown in Fig. 50.

The particular feature of the Cummer dryer is the manner in which the hot gases are distributed. Three-quarters of the heated air and gases from the furnace enter the cylinder by way of a number of $10\frac{1}{2}$-in. diameter hooded inlet openings in the cylinder, as indicated by the arrows in Fig. 53. The balance of the hot gases enters at the rear end of the dryer. The hot gases entering at the hooded inlet openings at the front end of the cylinder come in direct contact with the wet, cold material as the latter enters the dryer. By the admission of cold air through the sliding doors in the dryer setting, the temperature of the heated air and gases entering the dryer towards the rear end can be reduced to suit the nature of the fuel to be dried. Many grades of coal, more especially the high volatile qualities, become susceptible to injury or loss at high temperatures. The lowest temperatures, and the lowest circulation of gases, are found at the rear end of the cylinder, where the material has become dry and dusty. High temperatures are in this way applied where the material is wet and cannot be injured; moderate temperatures where the material is partly dried; and low temperatures at the rear or discharge end of the dryer.

As a rule when drying coal the Cummer dryer is provided with a dust-settling chamber. The exhaust fan for extracting the products of combustion and the

vaporised moisture is placed on the chimney side of this chamber, and is not directly connected to the head or feed end of the cylinder.

It has been stated that the provision of these dust-settling chambers is dangerous practice, in that air infiltration through cracks in the walls may be a means of igniting hot coal-dust and perhaps causing an explosion. Many dryers are in use in America with dust-settling chambers of this description; all the same, it is perhaps more prudent to eliminate them.

The indirect-fired dryer adopted by the Simon-Carves Co. consists of a rotary horizontal cylinder supported at one end by a ring resting upon rollers and at the other by a shaft and bearing. The cylinder is enclosed for nearly its whole length inside a brick chamber to which heat is applied, and as the cylinder revolves the coal passes through separate compartments so arranged as equally to distribute the coal. An exhaust fan is used with this equipment, and the ordinary chimney draft stack can be used, when necessary, for drawing off the evaporated moisture and products of combustion.

By enclosing the greater part of the cylinder within the firing chamber, not only is the coal in direct contact with the heated walls of the cylinder, but it is claimed that radiation losses are also reduced thereby. The hot gases enter the cylinder at the discharge end and pass through to the outlet or exhaust fan in the usual manner.

The initial cost of coal-pulverising plant is in a measure considerably increased by the comprehensive equipment that has to be provided for drying the coal and for conveying fuel to and from the dryers. The considerable space occupied by the usual types of rotary dryers, as referred to above, has great bearing upon the cost of buildings, and in order to curtail the space required for drying plant as much as possible, the Grindle multiple tube dryer has been introduced.

A Grindle dryer as installed for a complete plant is shown in Fig. 41, while Fig. 54 clearly indicates the arrangement of this novel drying unit. By forcing the coal to travel through a series of tubes fed from one common chamber, as each tube passes in front of the feed opening, the usual length of a single-shell horizontal dryer for equal duty is curtailed to a very great extent. This arrangement of small diameter parallel dryer tubes has also the effect of very considerably increasing the heating surface with which the coal comes in contact. Not only is the heating surface greatly increased as compared with some of the usual types of indirect-fired rotary dryers of usual pattern, but in the Grindle dryer the hottest gases do not come in contact with the dry coal. That the velocity of gases through the series of tubes is relatively low is another feature claimed for this type of dryer.

It will be seen that the material to be dried is first subjected to direct contact with the hot walls of the tubes, and subsequently to the flow of lower temperature gases as these pass back through the tubes to the feed end of the dryer; at this point an exhausting fan discharges the evaporated moisture and products of combustion to the atmosphere or cyclone dust collector in the usual manner.

The temperature of furnace gases in contact with the tubes at the wet coal or feed end is between 800° and 1000° F. The gases are then deflected back over

the tubes by bridge walls, and enter the dryer tubes at the discharge end at a temperature of about 250° F., finally reaching the feed end at about 150° F.

It will be seen that each tube contains a charge of fuel in course of drying; the weight of coal is thereby distributed and the tube wheel, as it may be termed, is approximately balanced. Less power is required to operate this type of dryer than is required for an unbalanced shell type dryer, wherein the fuel piles up against the direction of rotation.

Types A and B Buckeye Dryers are shown respectively in Figs. 55 and 56. Type A is an indirect-fired dryer intended for use in drying materials carrying high percentages of water, from 40 % to 90 %, and would, therefore, be suitable for the drying of coal sludge or peat. Type B is a semi-indirect type used for materials of lower moisture content, from 10 % to 40 %, and would be used for the drying of ordinary grades of coal.

In type A, the gases coming from the furnace are distributed evenly over that portion of the dryer shell which is enclosed in the furnace chamber, and the gases pass through tubes into the central tube, through which they pass to the discharge end of the dryers and return in contact with the fuel to be dried to the charge end. Under working conditions the furnace gas temperature is about 2000° F., and the final temperature at the exhaust fan is about 120° F. When drying material containing 90 % of water, evaporation tests show 10 to 15 lb. evaporation per lb. of coal used.

In type B, the hot gases from the furnace pass into the dryer cylinder through a central tube extending partly down the interior of the dryer. The coal to be dried is, therefore, heated by radiated or indirect heat until the gases have cooled down sufficiently for them to come into contact with the coal. It is claimed that the velocity of gases through the dryer is so low that little or no dusting occurs, and this type of dryer should be very suitable for drying coal of a light dusty nature without serious loss due to over heating.

In those types of dryers where the cylindrical shells enter the firing chambers, or pass through the latter, special smoke rings should be fitted to prevent flame and smoke from escaping from the fire chambers.

All dryer furnaces should be provided with natural draught chimneys arranged with by-pass dampers, so that when the exhaust fan motors are shut off, or the operation of drying is temporarily discontinued, the furnace gases can be passed to the stack; otherwise, overheating, and perhaps firing of coal lying in the dryer shells, would no doubt result.

It is usually considered good practice to revolve dryer cylinders at a speed not exceeding 5 r.p.m.; the slow revolution of the shell producing the best results. When dryers are run at 10 to 15 r.p.m. there is generally much loss through dusting.

In order to prevent warm moisture-laden air from being drawn into the "dry-coal" elevator at the discharge end of a dryer, and thereafter from following through into the dry-coal storage bin, the dry-coal conveyor and storage bin should be fitted with air vent pipes at the highest points, otherwise trouble may arise from condensation of moisture in the dry-coal storage bin. Also, in view of possible reabsorption of moisture by warm, dry coal when stored in bulk, every endeavour

should be made to carry out the evaporation of moisture in coal to the fullest extent possible.

The final temperature of dried coal prior to pulverisation is of very considerable importance, in view of subsequent storage, whether in crushed or pulverised form. If, at the end of the drying operation, the coal is overheated and contains too much moisture, say, for instance, a 10 % moisture coal is fed hot into a pulveriser mill and subsequently stored in a steel bin at 100° F., the temperature of the bin being at the normal atmospheric temperature of 60° F., a warm saturated atmosphere will be the result. The moisture in this atmosphere will condense upon the metal top and side plates of the bin, and will run down to the lower layer of pulverised coal. The delivery outlet to the feeders will become clogged with wet fuel, and the very conditions necessary for starting spontaneous combustion in the centre of the damp fuel will have been introduced.

For this reason every attempt should be made to dry coal to the standard of 1 % of free moisture, exception being made in the case of lignite and peat, which need not necessarily be dried below 5 % or even 10 % of free moisture. At the same time, the final temperature of dried coal should be as near to the atmospheric temperature as is possible. The thorough drying of coal becomes of particular moment when the fuel is to be conveyed in air to the burners. A uniform mixture of coal dust and air is then essential and it would become impossible to obtain regular feeding of pulverised fuel by means of the delicate Holbeck control apparatus, Fig. 57, if the fuel contains too much moisture.

The Drying of Brown Coal.

Some very valuable articles upon the subject of pulverised coal and firing with brown coal in Germany have recently been published in *Braunkohle,* from which periodical the following details and illustrations have been taken.

It is maintained that, in the preparation of brown coal, drying is a particularly important factor, and as no previous experience was available on the drying of this fuel, the company entrusted to two other firms the solution of this problem, viz. : the Berg Co., specialists in furnace construction, and the Decker Co., specialists in drying apparatus, and the combination of results presented by these firms has produced the very successful results referred to hereunder.

Walther Farner Decker Berg plants consist of a dryer, a mill, and a system of conveyor tubes to the furnace, in which the coal-dust is to be burnt. The Decker Dryer works by using direct heat or waste gases, and is shown in Fig. 60*b*. It consists of a drum with transverse longitudinal chambers somewhat similar to the Buttner Dryers.

The direct heating of brown coal containing high percentages of moisture is not economical, so the Decker Dryer is fitted up for waste heat firing; the gases travel in one direction and the sparks carried in the thick, dust-laden gases are at once quenched. The heat contained in waste gases is invariably insufficient for drying brown coal, and supplementary firing must, in consequence, always be provided.

Constant temperature is most important, and as this is quite unattainable

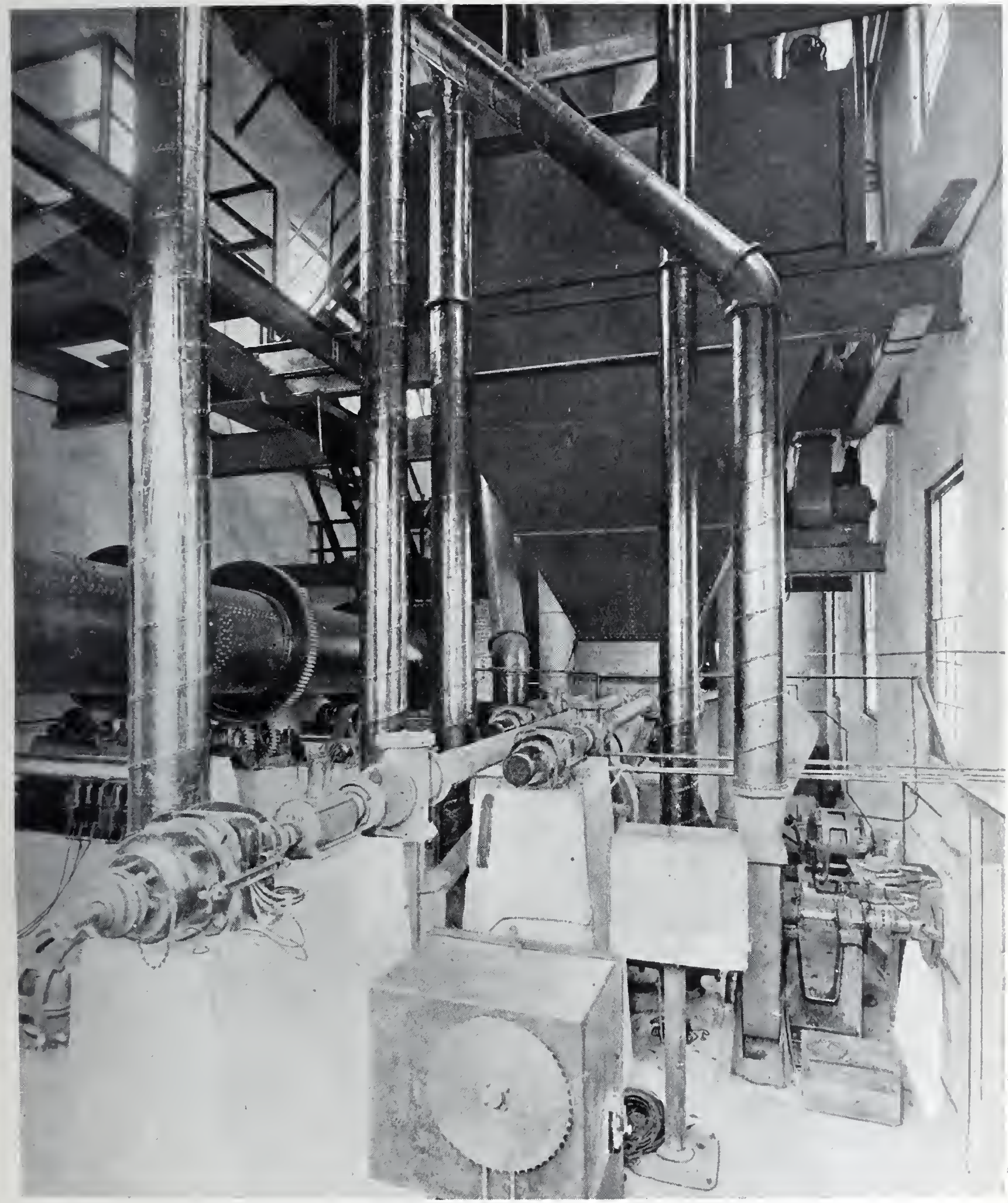


Fig. 57.—Interior View of Holbeck (Bonnot) Complete Plant, showing Rotary Coal Dryer and Fuel Feed Controllers.

A. A. Holbeck.] [The Bonnot Co.

[To face p. 162.

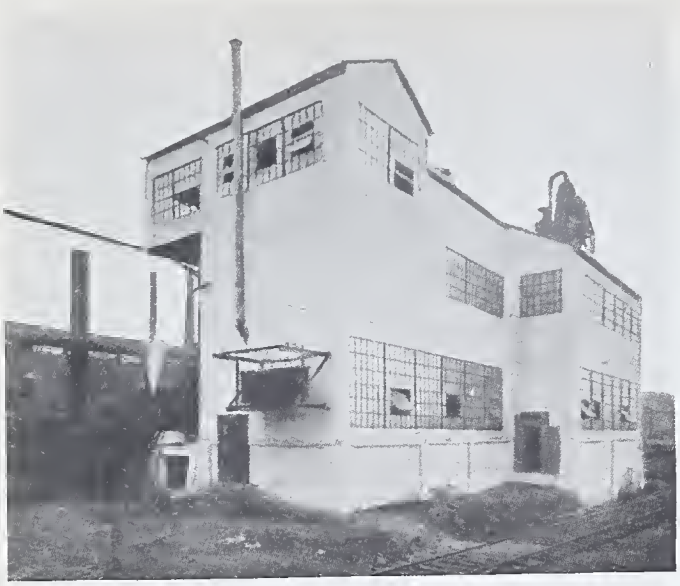


Fig. 58.—Ferro-concrete Pulverised Fuel Plant Building, showing Fuel Delivery Pipe (Quigley System).

Quigley Fuel Systems, Inc.]

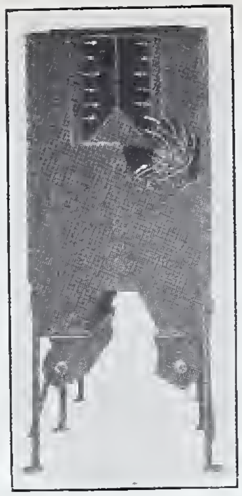


Fig. 60.—End View of Lopulco or Usco Coal Dryer, showing connection to Exhaust Fan.

International Combustion Engineering Corpn.]

Fig. 60a.—End View of Lopulco or Usco Coal Dryer, showing Flue Gas Connection to Dryer.

[*International Combustion Engineering Corpn.*

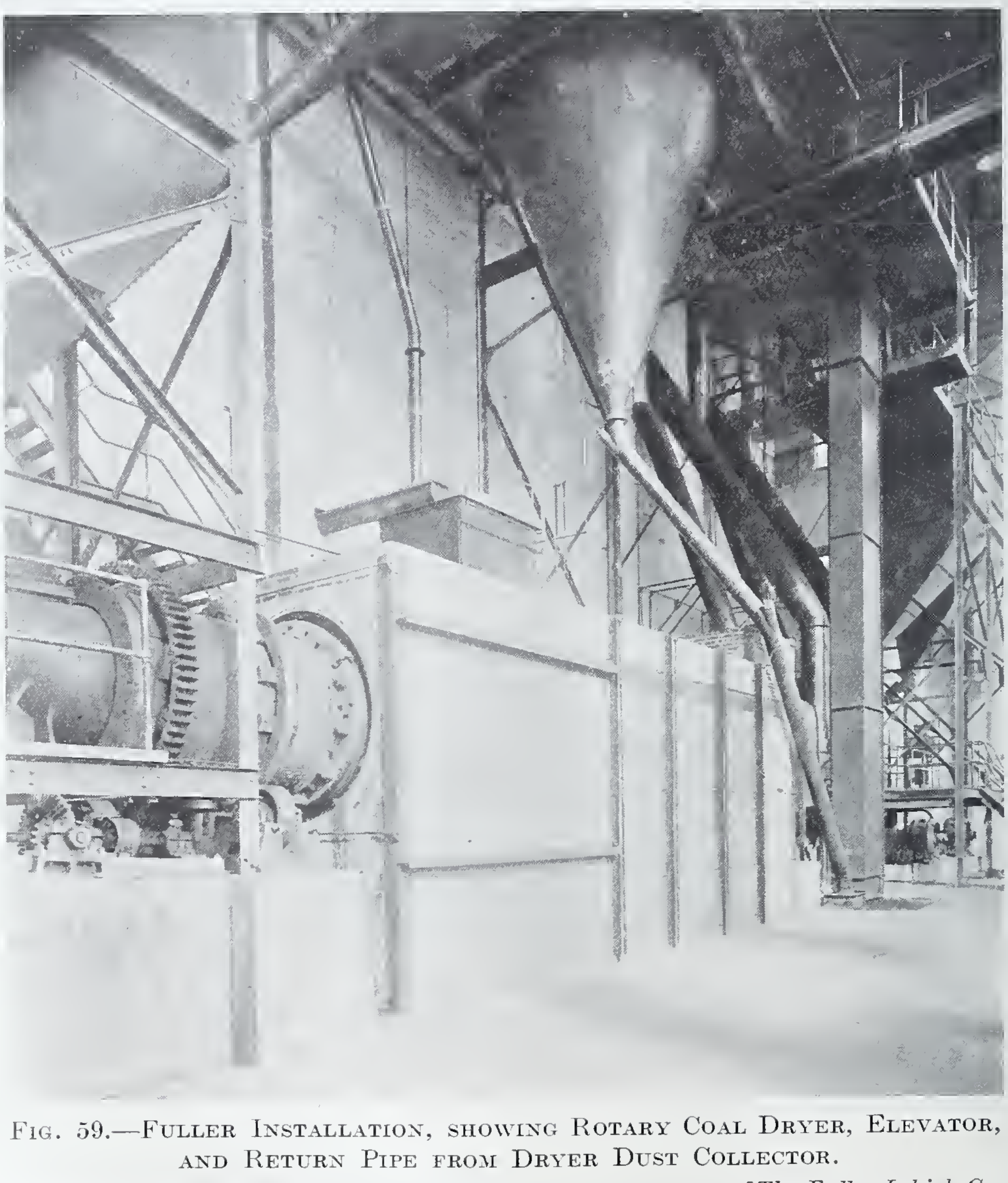


Fig. 59.—Fuller Installation, showing Rotary Coal Dryer, Elevator, and Return Pipe from Dryer Dust Collector.

The Fuller Engineering Co.] [*The Fuller Lehigh Co.*

with hand or mechanical grate firing, pulverised coal firing is essential. Firing with dry pulverised fuel is better for heating a dryer than using raw brown coal fired on a grate, owing to the absence of moisture in the dry pulverised fuel.

Decker Dryers are made in such manner that they cannot be overfilled, and the whole drum section is filled uniformly with fuel to be dried. This end is achieved by means of special channels, as indicated in Fig. 60*b*. The left-hand section shows the filling of the dryer cells, the coal subsequently falling from these channels in the manner shown in these two views. Under the influence of the exhaust draught, and due to the inclination of the dryer drum, the fuel passes slowly through the dryer, the time required for driving off the moisture being fixed by regulating the draught opening.

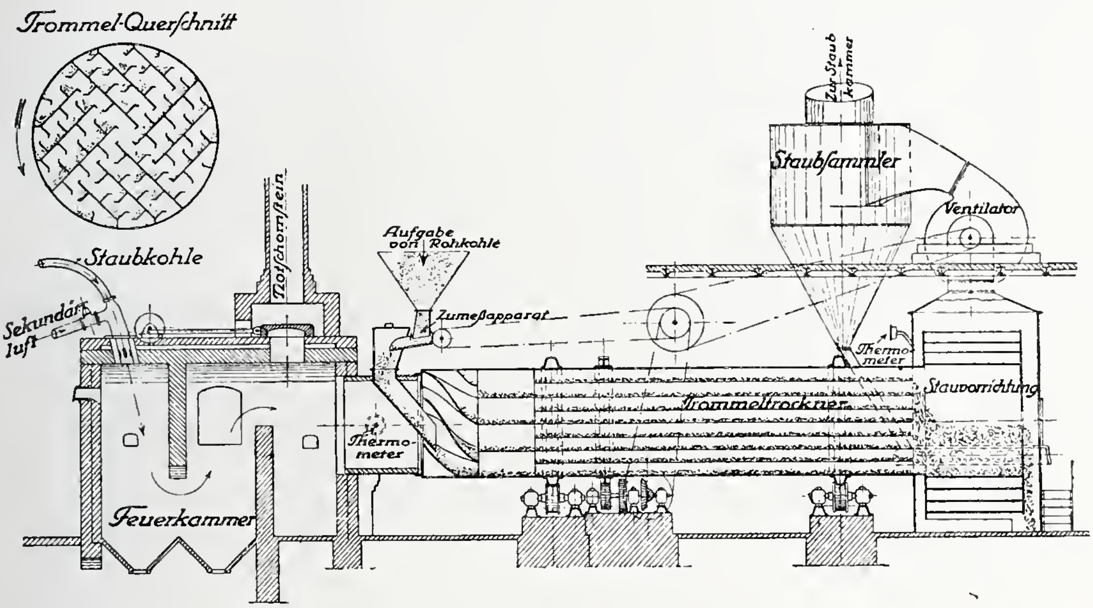


FIG. 60*b*.—" Decker " Pulverised Coal Fired Rotary Coal Dryer, with inset diagram of Distributor Channels. (*Braunkohle.*)

The power required for operating a dryer having a capacity of 100 tons raw brown coal per 24 hours is about 26 kw. = 624 kw. hrs., and taking 1 kw. = 3·6 kgs. raw coal of 2500 cals. gives a fuel consumption 2·24 % of the charge.

It is stated that 55 tons of dry coal will equal 100 tons of raw brown coal, reckoning 55 % initial water content and reduction to 18 % moisture. For this duty, the consumption of coal for power and the firing of the plant is 26 % of the total weight of wet fuel. A reduction of but 5 % initial moisture content means a considerable reduction in fuel used for drying. For instance, with 50 % moisture the total consumption of fuel for power and drying to 18 % final moisture is only 17 %. The final temperature of the coal is usually about 90° to 100° C. Fuel containing 18 % to 25 % water can be handled successfully in the special pulverising mills supplied with these plants.

Stationary or Static Coal Dryers.

Every endeavour has been made to devise an efficient coal dryer having no

moving parts in order to eliminate rotary cylinders and electric motors for operating same. The Usco Dryer designed by the Underfeed Stoker Company is now being used with success.

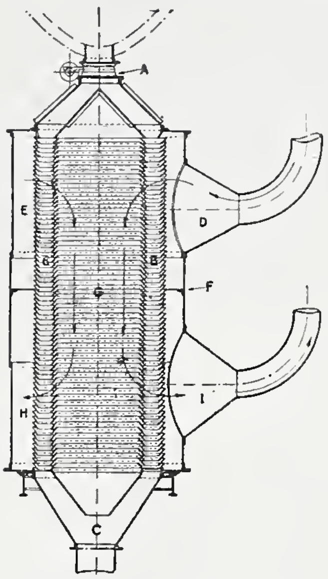


Fig. 60c.—Diagram of Usco Static Coal Dryer.

A raw coal inlet, *B* coal drying cavities or chambers into and through which the drying gases pass, *C* dry coal outlet, *D* waste heat (gases) from boiler diluted if required with atmospheric air, *E* hot gas chamber, *F* division plate between chambers, *E* and *H* collector chamber for spent gases and steam communicating with *I* pipe to evacuator fan.

The Lopulco or Usco Static Coal Dryer consists of a steel casing in which are located two rows of louvres or baffles on each side, and between these rows the raw coal passes by gravity from the bunker to the star feeder located at the bottom of the louvres. The star feeder provides for a uniform movement of the coal between the louvres, and is connected either to a dried coal bunker or to conveyors which convey the coal to the mills.

The stream of coal between the louvres provides a large surface of coal area, through which waste flue gases pass. These gases, which come in direct contact with the coal, remove its moisture.

The opening at the bottom of the dryer is an inlet which is connected to the boiler flues or stack. The gases are drawn through this opening, through the stream of coal at the bottom, back through the raw coal at the top, and thence out through the upper connection to the exhauster, which provides sufficient suction to overcome the resistance encountered.

By utilising the heat contained in the waste gases after passing through the economiser, the normal operation of drying coal of from 10% to 15% moisture can be carried out with an expenditure of about 3 kw. hrs. per ton of coal handled.

The capacity of such dryers as shown in Figs. 60, 60*a* and 60*c*, is 12,000 lb. of fuel per hour, assuming an initial moisture content of 10%.

When coal contains a greater quantity of moisture than 10%, then, by means of a by-pass arrangement, a portion of the hotter waste gases from the boiler is diverted to the coal dryer, and does not pass through the economiser.

By such a method as described fuel containing a high percentage of moisture can be dried by means of waste gases.

CHAPTER IX

PULVERISING COAL, FINENESS, MOISTURE, AND TYPES OF PULVERISER MILLS

Importance of Fine Dry Product—Departure from Standard of Fineness and Moisture—Temperature Rise of Fuel in Storage—Opinions as to Types of Mills —Ball and Tube Mills—Electrically Vibrated Separator Screens—Screen and Air Separator Mills—Wear and Tear of High Speed Mills—Pulverised Anthracite Coal and Coke—Fuel Feed to Mills and Testing for Fineness.

Importance of Fine Dry Product.

Standard of fineness and uniformity of product are very important factors governing the degree of success to be obtained when burning pulverised coal. The essential feature of fine pulverisation is emphasised by the well-known authority on pulverised-coal firing, A. B. Helbig, who made this clear in an address delivered at a meeting of a German commission appointed for the purpose of studying the various methods of applying fuel for heating purposes.

Helbig says that all early attempts to use pulverised fuel failed, first because the science of milling was not sufficiently far advanced to produce powdered fuel of the requisite fineness, and secondly because there was at that time no pressing necessity to work with coal-dust. The necessity for developing the technics of fine milling arose with the introduction into American and German cement manufacture of the rotary furnace, which can be economically heated only with powdered coal. For the last thirty years, America and Germany have been working side by side in this domain. Having regard to the difference in the eeonomic conditions of the two countries, it is easy to understand that, in Germany, pulverising machines of low velocity were preferred, whereas American industry was in favour of high-velocity pulverisers. In Helbig's opinion a standard system has not yet been established, and is not likely to be established in the future. In order to produce a pulverised fuel, that is to say, a very fine powder, the particles of the powder when ready for use must not adhere to one another. The percentage of water consistent with this condition depends very much on the physical nature of the fuel. Success has been obtained in pulverising low-temperature coke containing 25% of water, but the subsequent pressure in the feed screws caused the particles to cohere. Brown coal with 15% to 17% of water can be pulverised and burns smoothly. The percentage of water consistent with proper working must, therefore, be decided according to circumstances. It may, however, be stated generally that the efficiency of the mill per unit of work increases with the degree of dryness, and that doubtless there exists for every fuel a definite degree of moisture, with which the sum of the drying and pulverising work is a minimum.

The degree of fineness to which fuel should be reduced varies with the density of the substance; with its percentage of volatile constituents; and, above all, with

the combustion areas and passages available in the furnace. With any dense substance, the combustion of the grain must proceed from the surface inwards, and, therefore, in order to shorten the period of combustion, the grain must be pulverised as finely as possible. A percentage of 16 to 18 of volatile constituents in coal admits of the maximum size of grain. With a poorer or a richer coal, finer pulverisation is needed, as the time required for the combustion of the grain is in each case greater.

Obviously, it makes a very considerable difference whether pulverised fuel is fed into a rotary furnace with a flame length of 10 to 20 m. or more, or whether it is to be burnt, for example, in the confined space of a locomotive firebox. In the latter case, it must, of course, be pulverised much more finely, in order that complete combustion may be achieved. It will be gathered, therefore, that it is impossible to prescribe a definite fineness in every case. One thing, however, is certain; the finer the powder the better the combustion process. The contention that the same result can be obtained with coarser powder is based on a misapprehension of the facts. The only limit to the fineness of the dust is the expense of grinding.

In order to settle once and for all the suitability of fuels for pulverisation, G. Polysius of the Dessau Machine Factory, on the 30th November, 1920, in the presence of various interested persons, burned coal and low- and high-temperature distillation coke in pulverised form, without combustible residue, in a test furnace, and thereby proved that the possibility of pulverised-fuel combustion is not affected by the percentage of volatile constituents, but depends only upon pulverisation being of the requisite degree of fineness.

The standard of fineness that has been adopted throughout the United States for pulverised coal is such that 85% of the product will pass through a 200-mesh screen (40,000 holes to the square inch) and 85% through a 100-mesh screen (10,000 holes to the square inch).

For boiler firing and for use in metallurgical furnaces fine grinding is essential, otherwise instantaneous and complete combustion is impossible, the result of firing relatively coarse fuel being loss of unburned carbon in the flue dust, and in the slag or clinker in the combustion chamber.

Notwithstanding recent contentions that the standard of fineness stated above is unnecessary, it has on very many occasions been conclusively proved in practice that the additional power expended in order to obtain this standard of fineness is more than paid for in other ways. This was clearly exemplified in connection with plant which worked unsatisfactorily when pulverised coal was used of a fineness of 88% through a 100-mesh screen. But, after raising the degree of fineness to the standard before mentioned, definite tests showed an increase in furnace efficiency of 12%, and the previous troubles due to heavy clinker formation were entirely removed. It is for such reasons that, when the fuel is to be burned in close contact with refractory linings or in combustion chambers of confined areas, the coal should be reduced to the standard of fineness specified.

It is perhaps as well to restrict the use of screen separation mills to the pulverisation of coal containing not more than 6% or 7% of moisture, otherwise there may be trouble through the closing up of the screens. Coal as it leaves the dryer should not contain more than 1% of moisture, but in some cases where fuel, such as peat,

cannot be dried to within 10% or even 20% of the total moisture, or where, for other reasons, it is desirable to leave 10% or 15% of moisture in the fuel, as in the case of lignite, then it becomes almost essential to use air-separation mills. Lignite containing 13% moisture has been successfully pulverised in screen mills, but one would not instal screen mills to operate normally under such conditions.

Departure from Standard of Fineness and Moisture.

Rigid adherence to the standard of fineness may not be necessary under skilled supervision of the burning of the fuel, but for good results in all-round works practice the finer the fuel the greater the degree of success.

The contention that fineness must be equal to 85% through a 200-mesh screen and that moisture must be reduced to a small percentage has been disputed by some engineers, and, because the use of fuel in pulverised form has assumed such an important position in America, it was considered advisable to make scientifically accurate tests at the United States Bureau of Mines Laboratories, Washington, in order to determine the degree of fineness of fuel necessary for successful firing, and to fix a limit of moisture content.

A boiler was arranged with suitable combustion chamber for burning fuel at the rate of 1700 lb. per hour. In a series of tests carried out with the coal, as usually prepared to the standard degree of fineness, the efficiency varied from 79% to 84%. The higher figure was obtained when the boiler was worked at about its normal rate, and the lower when it was given a 67% overload. To determine the effect of fineness of pulverisation upon efficiency, four separate tests were carried out with fuel 89% to 93% of which would pass through the 100-mesh screen, and only from 64% to 70% through the 200-mesh screen. The efficiencies obtained when using the coarser fuel in the four trials ranged from 81% to 83%, with the boiler working at a little over its rated capacity, and it was contended that the completeness of combustion was more a matter of a proper furnace and burner design than of the degree of fineness of the coal. Combustion results were closely analogous for the two degrees of fineness; the percentage of carbon in the ash and flue dust when burning the " coarse " coal was about 0·7% and for the " fine " coal about 0·6%.

A series of tests was carried out on this boiler with fuel containing 6% or 7% more than the standard of 1% of moisture, and it was found that the average decrease in boiler efficiency due to moisture above 1% in the fuel was less than 1%.

The conclusions arrived at after these tests were made were that the evaporative power that can be developed in a boiler using pulverised coal appears to depend, to a very great extent, upon the size and shape of the furnace, and that the best results were obtained when the coal was burned at the rate of 1 lb. to 1½ lb. per hour per cu. ft. of combustion space. The results were also good over a range varying from ½ lb. to 2 lb. of fuel burned per hour.

As pointed out elsewhere, it is not disputed that the standard of 1% of moisture is not essential for the successful grinding of coal; it is, however, most advisable to endeavour to obtain this result when pulverised fuel has to be stored in bins and delivered through screw conveyors or by other transport systems previously referred to.

Temperature Rise of Fuel in Storage.

The temperature at which fuel is stored is a very important factor as regards safety, and the more so when it contains moisture in excess of 1%. The final temperature of the fuel at the discharge of the dryer should be low, for additonal heat may be transferred to the fuel during the process of pulverisation.

Calculations as to the temperature rise due to the actual crushing of coal have been recorded by Professor Henry Briggs in a paper relating to Spontaneous Combustion in Coal Produced by Crushing. This paper was read at a meeting of the British Institute of Mining Engineers, and for the calculation of the power absorbed in pulverising coal some of the data sent in reply to a questionnaire sheet (facing this page) was made use of.

Extracts from a review of this paper, as published in *The Iron and Coal Trades Review*, November 17th, 1922, and reproduced below, are of considerable interest to pulverised coal engineers :—

" The following facts are obtained from L. C. Harvey's monograph on " Pulverised Coal Systems in America."

" The usual practice in America is to break the coal through a 3 in. ring before it is fed to the pulveriser. The standard degree of fineness adopted throughout the United States for the dust used in industrial plants is 85% through a 200-mesh screen and 95% through a 100-mesh screen. We may, therefore, judge the average size of crushed particles to be about $\frac{1}{300}$ in.

" By circulating a questionnaire Harvey ascertained, among other things, the power expended in daily practice in pulverising bituminous coals at eight plants. A variety of mills were used for the purpose, but the results were found to be of much the same order, ranging as they did between 12·8 and 20·8 kw. hours per short ton (2000 lb.). The mean of the eight is 16·4 kw. hours per short ton. If we may allow an average efficiency of 50% for these mills we get :—

" Work expended in crushing 2000 lb. of bituminous coal = 8·2 kw. hours. Or work expended in crushing 1 lb. of coal = 10,890 ft. lb.

" Applying calculations set forth by the author in the present paper it is found that the heat developed in crushing bituminous coal = 0·00036 B.Th.U. per sq. in. of fractured surface; or = 0·014 gramme-calorie per square centimetre of surface. The result averages up all conditions of cleavage present in the coal. The heat evolved in splitting along a cleat-plane will be less than the amount expressed, while that produced at a conchoidal fracture will be more.

" In view of the numerous instances in which fires have originated in shale, it is advisable to extend the inquiry to include that rock. Mr. A. L. Lovatt has been kind enough to carry out a special set of tests in order to determine the power consumed in grinding the soft shale used in stone-dusting at Birchenwood Collieries, North Staffordshire. The shale, which has an inferior plane cleavage, is from the roof of the Birchenwood Seam, and is ground in a Scholefield No. 1 ' Ideal ' ball-mill. The following are Mr. Lovatt's figures :—

TABULATED ANSWERS GIVEN ON QUESTIONNAIRE SHEETS SENT TO AMERICAN USERS OF PULVERISED COAL.

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]		[illegible]	Maintenance only [illegible] cents Total cost, $1·25	[illegible]	[illegible] for burners.
[illegible]	One Reverberatory Copper Furnace	Cheaper than [illegible] maintain [illegible] temperature	[illegible]	1	[illegible]	[illegible]	2	Raymond	[illegible] each	1·0		12·8	[illegible]	[illegible]	Total cost, $1·25	[illegible]	Screw Conveyors used to transport coal 200 ft. and lift 60 ft. Total power for conveyors 1·9 kw. per ton and overall maintenance for same 0·18 cents per ton.
Bituminous [illegible] 16 Stirling water tube [illegible] Total 161,800 [illegible] 125,000 lb. [illegible] 70	Reverberatory [illegible] Screw Feeder with [illegible] transmission and Warford Burners used on Furnaces	7–8 tons charge per ton pulverised coal. Old fuel rate was 4 tons charge per ton hand fired coal	By the use of pulverised coal output of furnace [illegible] been [illegible] tons to 380 [illegible]	1	Raymond [illegible]	[illegible] total	12	Raymond 5 Roller	4·4 each	6·2	5·0	14·88	—	10·8	Maintenance only 17·7 cents. Total cost, $0·325	31·0	Power for blowers and burners 8·0 kw. per ton. 200 ft. of 14 in. Screw Conveyors conveying power 0·03 kw. and cost 1 cent per ton.
[illegible] 118	[illegible] Burners and Feeders [illegible] on boilers			1	Ruggles-Coles	6½	2	Raymond 5 Roller.	5 each	3·73		17·9	0·007	·056	$0·325	12·65	Results obtained were so satisfactory that new Power Station to be equipped with pulverised coal shortly.
Bituminous [illegible] 6 Babcock and Wilcox [illegible] type 10,730 and 20,700 lb. per hour [illegible] 183 200	Fuller Engineering Co's and Lopulco Feeders and Burners made by users		Screw Conveyor [illegible]	2	Fuller-Lehigh.	22 total	3 1	Fuller Lehigh Raymond.	—					—	Maintenance only 13 cents	23·8	Confirmed advocates of pulverised coal firing, but had some little trouble with plant at first.
[illegible]	Used for several years with great success on a number (not stated) of Annealing Furnaces. Also in use for one year on 20-ton Melting Furnace	Completely successful on Annealing Furnaces but so far the results on the Melting Furnace have been rather disappointing with charges of more than 8 tons.	Suggest [illegible]	1	Ruggles-Coles 5 ft. 30 ft.	8	1	Fuller-Lehigh 42"	4·5			—	—		—		
[illegible]	One Open-hearth Steel Furnace. One Ingot Re-heating Furnace	525 lb. of pulverised coal per ton steel as against previous 650 lb. coal per ton when using producer gas. 550 lb. pulverised coal per ton in re-heating furnace	Open-hearth Furnace [illegible] non-regenerative [illegible] non-recuperative [illegible] Burner with [illegible] and fan air supply. Reheating Furnace [illegible] pit design, Fuller Burner low pressure air	1	Fuller-Lehigh.	10	2	Fuller-Lehigh	3 each	—	2	—	0·747	22·42	Maintenance only 24·42 cents	26·177	Results would be excellent on Open-hearth Furnace if furnace was properly designed for pulverised coal. Results not so good on re-heating with pulverised coal as with producer gas.
[illegible]	50 ton Open-hearth Steel Furnaces.	578 lb. pulverised coal per ton of steel.	Pulverised coal is used to supplement natural gas supply, for which fuel the furnaces were originally designed, so that the results obtained are not so good as they would be with a furnace designed for pulverised coal.	2	Fuller-Lehigh	15 each.	8	Fuller Lehigh 42"	3½ each.	2·61	—	17·6	—	—	—	54	Generally the plant has given satisfactory service with the possible exception of the burners which are modified Fuller type. Chief trouble with pulverised coal is due to ash dust in checkers and flues, as furnace was not made for pulverised coal.
[illegible]	Continuous Billet Heating Furnaces, heating 4 in. – 1 in. Billets. Fuller and Bergman Burners used with Screw Type Feeders.	202 lb. pulverised coal per ton of billets heated.	Pulverised coal used to supplement natural gas supply, for which reason results are not as good as with a plant operating continuously on pulverised coal. Some trouble with burners and also with fusing of ash and formation of slag.	1	Fuller-Lehigh.	10	2	Fuller-Lehigh 42"	3½ each.	1·03		20·8	—	—		27·67	Plant generally satisfactory except for some difficulties due to slag formation in furnace.
[illegible]	6 Open hearth Furnaces. 3 Billet Re-Heating Furnaces.	Open-hearth Furnaces 700 lb. per ton producer gas. 650 lb. per ton pulverised coal. Billet Furnaces— 350 lb. per ton hand fired. 223 lb. per ton pulverised coal.	Plant appears to be generally highly satisfactory. Present Screw Conveyor system is being replaced by a compressed air system. Syphon feed used for Burners.	2	Cummer	10 each.	3 1	Raymond Raymond	5 each. 1	—	0·246	15·5	—	—	Maintenance only 21·1 cents.	21·47	They state that in their opinion pulverised coal is highly satisfactory for all types of furnaces not using regenerators or recuperators.
[illegible]	Continuous Billet Heating Furnace and Bolt and Nut Bar Heating Furnaces. Size and number not given	Not yet in a position to give any reliable figures as to results and costs.	Covert Screw Feeders and plain pipe Burners used.	1	Ruggles-Coles	10	—	—		—	—	—	—	—			Do not think pulverised coal has any advantage over natural gas at 25 cents per 1000 ft.

* Normal price of Industrial Coal—$2·50 to $4·00 per ton at the works (1923)

† V.M = Volatile Matter. F.C = Fixed Carbon.

[*To face p.* 108

" Amount of stone dust ground	10 cwt.
Time taken	$2\frac{1}{2}$ hours.
Energy consumed by driving motor during the test . .	11·37 kw. hours.
Energy consumption when mill was driven with feed cut off for $2\frac{1}{2}$ hours	8·0 ,, ,,
Energy actually consumed in grinding stone dust (by difference)	3·37 ,, ,,

" A sizing test on an average sample of stone dust gave the following proportions by weight :—

Over Mesh.	%	Over Mesh.	%
0–10	Nil.	60– 90	16·4
10–20	1·2	90–120	12·2
20–30	1·4	120–200	11·6
30–60	2·0	Under 200	55·2

" We may assume the average size of particle to be about $\frac{1}{250}$ in. The heavy expenditure of energy (8 kw. hours) when the mill was running empty is in part explained by the fact that the motor is driving line shafting and elevators in addition to the mill. As the balls were in the mill during this ' blank ' experiment, energy was consumed in lifting and rolling them; as that energy would for the most part be utilised in crushing when the mill was working normally, the assessment of 3·37 kw. hours as the energy actually involved in crushing the half-ton of shale is, therefore, an underestimate, and it is preferable to take the figure 4 kw. hours in its place. We may now write : Heat developed in crushing Birchenwood shale = 0·00077 B.Th.U. per sq. in. of fractured surface ; or, 0·030 gramme-calorie per square centimetre of surface.

" The term ' mass temperature ' is used to signify the temperature of the mass of mineral after the heat developed in crushing has uniformly permeated that mass.

" (*a*) Bituminous Coal : Taking the average specific heat as 0·27, and assuming the whole of the work done in the pulveriser to be converted into heat, the heat developed in crushing average bituminous coal to an average size of 1–300 in. = 10,890 ft. lb. = 14 B.Th.U. per lb. The resulting rise of mass temperature = $\frac{14}{0 \cdot 27}$ = 52° F. (29° C.). If crushing suddenly takes place in a mine at a spot where the normal temperature is 75° F., crushed particles of the size stated will reach a temperature of about 127° F.

" (*b*) Coal-measure Shale : In like fashion, taking the specific heat as 0·18, the rise of mass temperature in reducing shale to an average size of $\frac{1}{250}$ in. = 68° F. (38° C.)."

The specific heats referred to by Professor Briggs, for coal of various grades are :—

	Specific Heat.	Authority.
Coal (unspecified, 0° to 12° C.)	0·312	Hecht.
Gas coal (24° to 68° C.)	0·204	Bettendorf and Wullner.
French gas coal	0·3145	Dewar.
Bituminous coals	0·2–0·4	Threlfall.
Coal-measure shale (sp. gr. 2·64) Birchenwood colliery, North Staffs. . .	0·17	Malpas.
Coal-measure shale (sp. gr. 2·05) Niddrie colliery, Edinburgh	0·23	,,

The test figures obtained when crushing the shale are quoted herein as a possible indication of the degree of heat that would be developed when harder grades of coal and coke are pulverised.

Opinions as to Types of Mills.

The consensus of opinion upon the grinding of coal appears to be in favour of pulverising soft fuel in high-speed mills, and hard fuel in ball or tube mills. In the former, output is greater for power expended, but the wear and tear of pulveriser rolls or rings is a heavy item and in excess of that for ball and tube mills.

Much information on this subject of grinding is given in *The Journal of the Engineers' Club of Philadelphia*, February, 1921, in which R. H. Vail, after fourteen years' experience of pulverised coal preparation, says :—

" It is my opinion that it will be found in the long run that the pulverising of anthracite will be most economically done in some form of tube mill using balls as the grinding medium.

" This opinion is based on three leading facts : First, anthracite is surprisingly abrasive ; second, the bituminous-coal mills of the ring-roll type have not given satisfactory results when grinding the abrasive anthracite ; third, the ball-tube mill is to-day the standard fine grinder for abrasive materials in our two greatest grinding industries. Now, it may be that the ring-roll type of mill using harder wearing surfaces will be employed for small capacity operations, but it seems to me that practical constructive limits for the size of these mills, the expense of replacing wearing parts and the interruptions to operation will prevent their competing with the ball-tube mills at installations where large capacity, continuity of operation and easy replenishment of the grinding medium are desired.

" If ground dry, I think that anthracite will be best pulverised in the ball-tube mill, equipped with direct air suction."

And further, the following observations are made :—

" Omitting consideration of buhr-stone and Chilean mills because of their small capacities, I shall refer briefly to the types of mills generally available for the fine grinding of minerals. These may be divided into two broad classifications, which I have designated as :—

(A) Ring-roll Mills ;
(B) Ball-tube Mills.

" Mills of Class A or ring-roll type are the Raymond, Bonnot, Fuller, Kennedy, Griffin, Sturtevant, Kent, Kreutzberg, etc. Operators after a short trial of these mills are looking elsewhere for apparatus to grind the abrasive anthracite. The fatal defect of the ring-roll mill, I think, lies in the attempt to grind an abrasive material between what may be termed, for lack of a better expression, ' fixed wearing surfaces,' the renewal of which is expensive. Some improvement in results with ring-roll mills may be looked for if harder wearing surfaces be used, but inasmuch as this Huntingdon type of mill has been replaced in the grinding of metalliferous ore

by the crushing roll and the ball-tube mill, I pass to the consideration of this last type of fine grinder.

" Mills of the Class B or ball-tube type consist of essentially a rotatable cylinder or tube in which the grinding media (usually balls) are dropped on the material to be pulverised. There are some slight variations in the shape and the divisions of the tube, but the Class B type include the original tube or pebble mill, the short tube or ball mill, the combination ball-tube mill, the rod-tube mill, which is a cylinder using rods as the grinding medium, and the conical ball mill, which is in effect a cylindrical ball mill with the ends in the form of the frustum of a cone. The ball mills of different makers have some variation in their methods of feeding and discharge, but the grinding principles are practically the same in all. These mills include the Krupp, Kominutor, Triburator, Marcy, Hardinge, Marathon, and numerous variants of the standard tube mills made by the well-known manufacturers of mining and cement machinery."

" A few of the outstanding rules relating to the ball mill operations are appended :—

" Speed of mill should be such that the balls are raised to a point that will permit them to drop for the maximum distance; speed varies inversely with the square root of the inside diameter of the mill; the proper operating speed increases with the ball load.

" Ball charge may vary between 20% and 60%, but with economy only between 25% and 50%, maximum efficiency being with a 40% ball load.

" Size of balls should be such that when dropping they will crush the largest piece of material to be ground; the amount of crushing done depends on the number of blows struck and on the work done by each blow; the number of blows can be increased by increasing the number and decreasing the size of the balls. Small balls, when of sufficient size, give better tonnage and more uniform product than an equivalent weight of larger balls. To give an idea of the operation of the ball mill, Davis calculated that in an 8-ft. ball mill running at 22 r.p.m. with a 28,000-lb. charge of 2 in. balls, there will be an average of about 1,000,000 blows per minute, each blow being equivalent to dropping a 2-in. ball about 5 ft.

" Uniformity of product is furthered by correct ball size and regular feeding.

" Every operation has peculiarities and the speed, ball load and size of ball, while starting with the average of empirical results on similar material, should be studied to obtain the conditions of maximum efficiency for each particular material. Once these are found it is easier to keep the ball mill to average performance and with less interruption of operation than any other grinder of abrasive material."

Ball and Tube Mills.

Anyone wishing to make a thorough study of the question relating to the grinding of materials should consult the very exhaustive work of E. W. Davis, whose conclusions are published in Vol. 61 of *Transactions of the American Institute of Mining and Metallurgical Engineers*, under the title " Fine Crushing in Ball Mills."

In modern German plant one finds nearly everywhere slow-running grinders

with a large area of crushing, mainly of the ball and tube-mill type. The larger amount of power consumption as compared with high-speed machinery does not particularly matter here. Ball and tube mills are, as a rule, located one over the other, so that the grist produced by the ball mill can go directly to the tube mill and there be converted into the fine powder required.

In order to improve the screening action, several types of ball mills have been placed on the market; for example, the Zementor Mill, Fig. 61, of Polysius, Dessau, Germany. Contrary to the usual practice in ball mills, this construction has unperforated crushing plates, these plates being located between the walls in such a manner as to form stages with each other. With this construction, the grist is forced to pass over the entire path of the grinding area, then over the sieve, and the coarse material is returned into the grinding drum.

The high cost of foundations which such an arrangement involves, and the effort

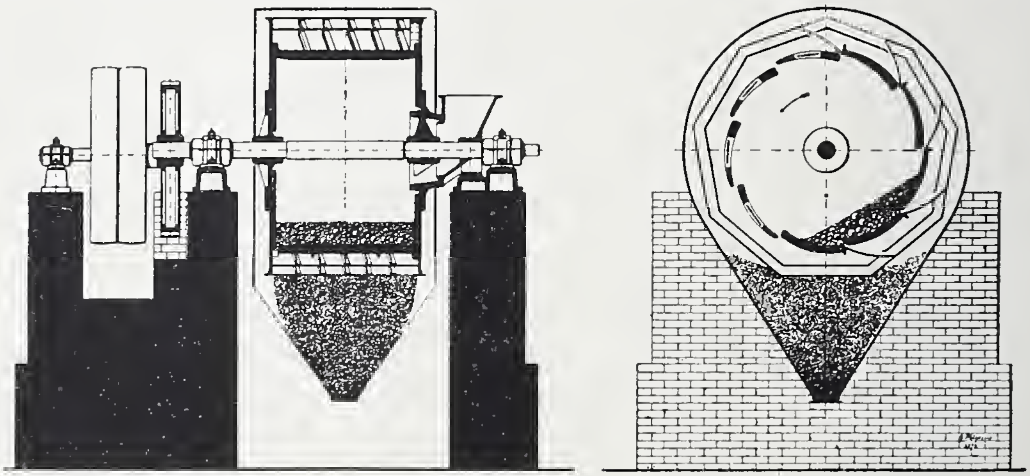


Fig. 61.—Polysius "Zementor" Ball Mill. (*G. Polysius, Dessau.*)

to simplify still more the grinding, led to the design of a machine which could carry out the crushing and fine grinding in one continuous series of operations. This resulted in the design of a combined crusher and pulveriser forming one cylinder, a particularly simple design. This type of machine, the "Solo" Mill, Fig. 62, is likewise built in Germany by G. Polysius, Dessau, and consists of a seamlessly welded sheet cylinder running in circular bearings. This cylinder is divided by a wall into two chambers: one, the crushing chamber with hard steel plates and steel balls, and the other, the fine grinding chamber with Silex lining and quartz stones. The crushing chamber is surrounded with screens, and is enclosed in a sheet steel jacket, and can crush pieces as large as a man's fist. This grist then falls through slots at the end of the crushing chamber upon screens, over which it travels, just as in the Zementor, to the admission side of the grinding mill. What remains over the screen is carried back into the crushing chamber, while that which passes through the screen is delivered to the fine pulverising chamber.

A convenient arrangement of "Solo" mill with rotary coal dryer above so that coal falls by gravity into the mill is shown in Fig. 65.

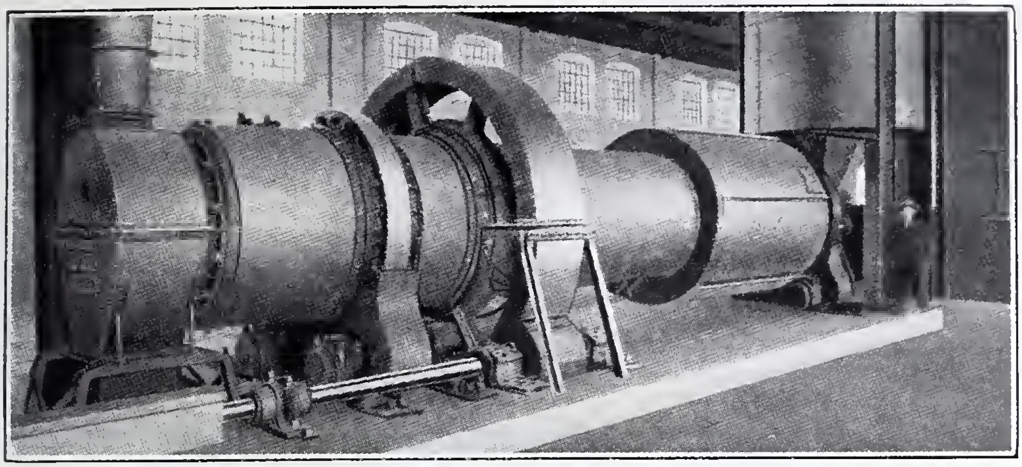


Fig. 62.—Polysius Combination Solo Ball and Tube Mill.

G. Polysius, Dessau.]

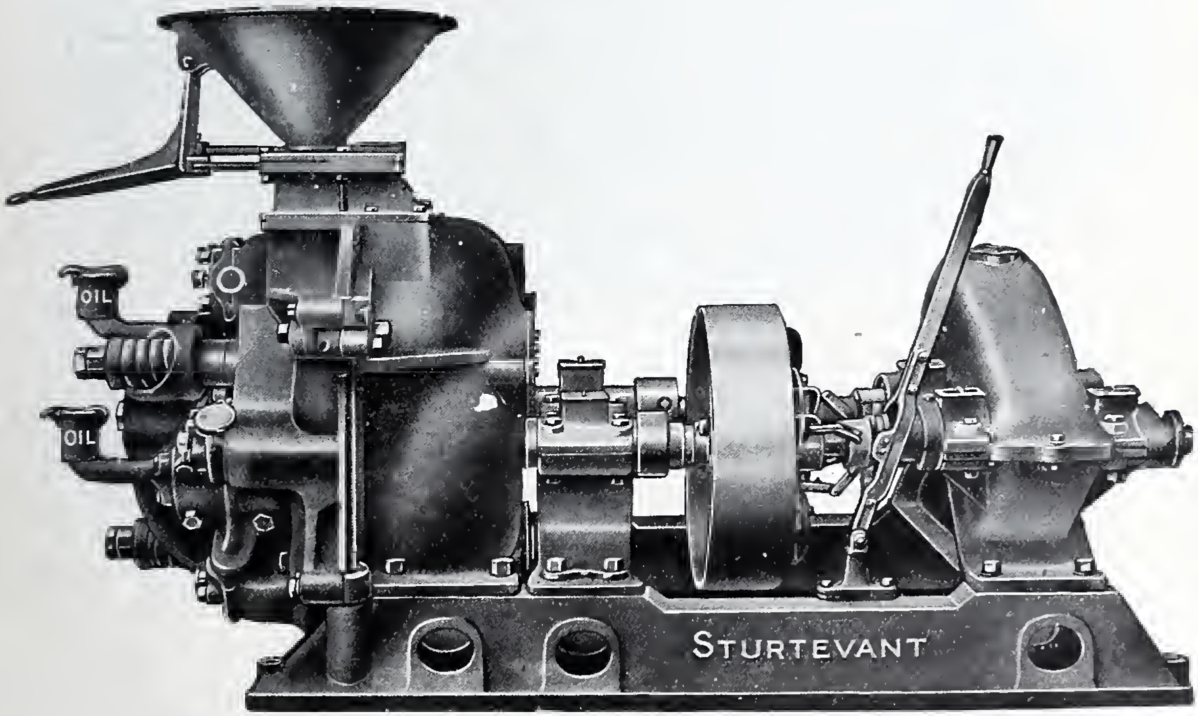


Fig. 63.—Sturtevant Ring Roll Mill.

The Sturtevant Engineering Co., Ltd.]

[*To face p.* 172

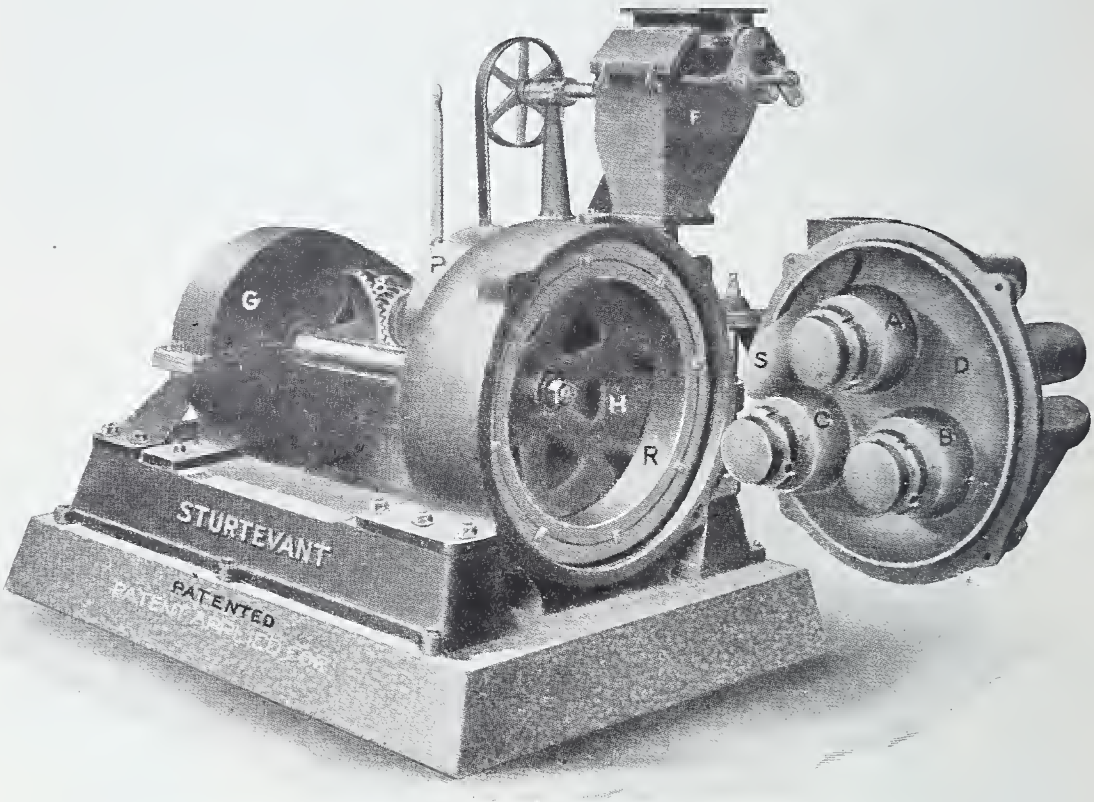


FIG. 63*a*.—STURTEVANT RING ROLL MILL (OPEN).

The Sturtevant Engineering Co., Ltd.]

As compared with the vertical high-speed type of pulveriser mills, to which must be fed fuel not larger than about 2 in. cube, the ball or tube mill will deal with coal containing pieces of 4 in. or 5 in. cube.

For the initial breaking down of hard abrasive fuel to, say, the 20- or 40-mesh stage, the Sturtevant ring-roll mill would be very suitable. This is illustrated in Figs. 63 and 63*a*. It has special features in that the grinding ring is revolved around rollers fixed upon rigid shafts. The rollers are held by powerful tension springs against the grinding ring, so that the maximum of pulverising effort is exerted without undue loss of power in bearing friction. The mill is of the horizontally driven spindle type, thereby making it a simple matter to drive by belting from a motor or from shafting. The product from this machine would be delivered into a storage bin or direct into a tube mill.

Ball mills of the Hardinge type, Fig. 66, have been largely used in the reduction

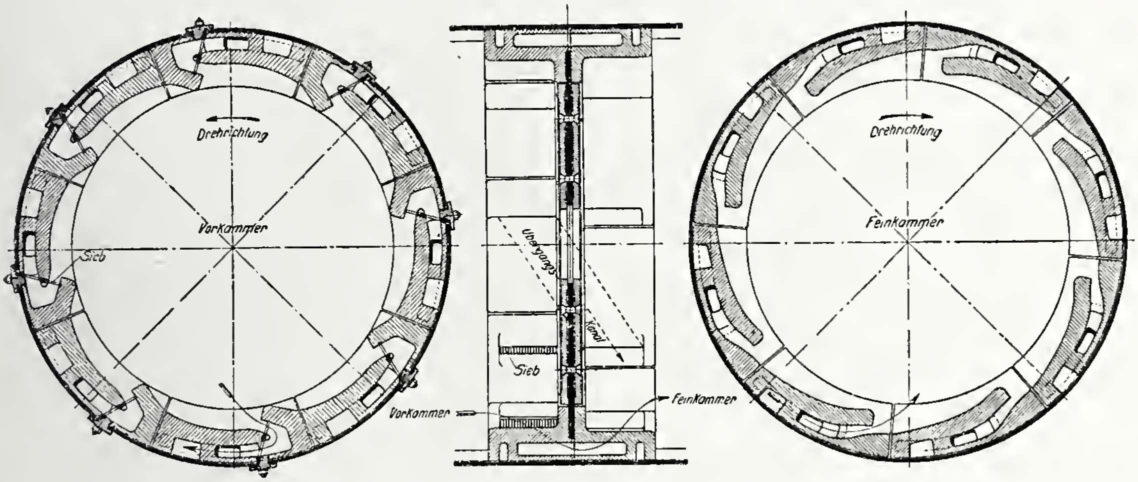


Fig. 64.—Sections of Lining Plates in Krupp Tube Mill.
Dr. Ing. Friedrich Münzinger. Kohlenstaubfeuerungen für ortsfeste Dampfkessel.

of mineral ores, but not to such a general extent in the pulverisation of coal. At the Lytle plant of the Susquehanna Collieries Co., Minersville, Pa., Hardinge ball mills as shown in Fig. 79 are used for pulverising the anthracite culm, a waste fuel previously dumped as of no value prior to the equipment of the colliery boiler plant for firing with this fuel in pulverised form. Fuller mills are also installed.

Ball mills, such as the Hardinge Mill illustrated, operate on the principle of a multiplicity of grinding bodies rolling in a rotating conical drum supported on hollow trunnions, through which the material passes into and out of the grinding zone. The grinding bodies in rolling and dropping grind and crush the material.

Owing to the conical shape, a condition exists in the mill which causes a natural segregation of both the grinding media and the material being ground. The coarse material, on entering the mill through the hollow feed trunnion, is crushed by the large balls (or pebbles) which always remain near the feed end, where the diameter is largest, owing to the classifying action of the cone. As the particles are broken down they automatically work their way forward, being subjected to a gradually

diminishing breaking and crushing effect as they decrease in size. The particles undergoing reduction reach the required degree of fineness and the discharge opening at the same time. This automatic classification of both the materials being reduced and the grinding media, proportions the energy expended to the work required; in other words, the fundamental principle of grinding is being obeyed.

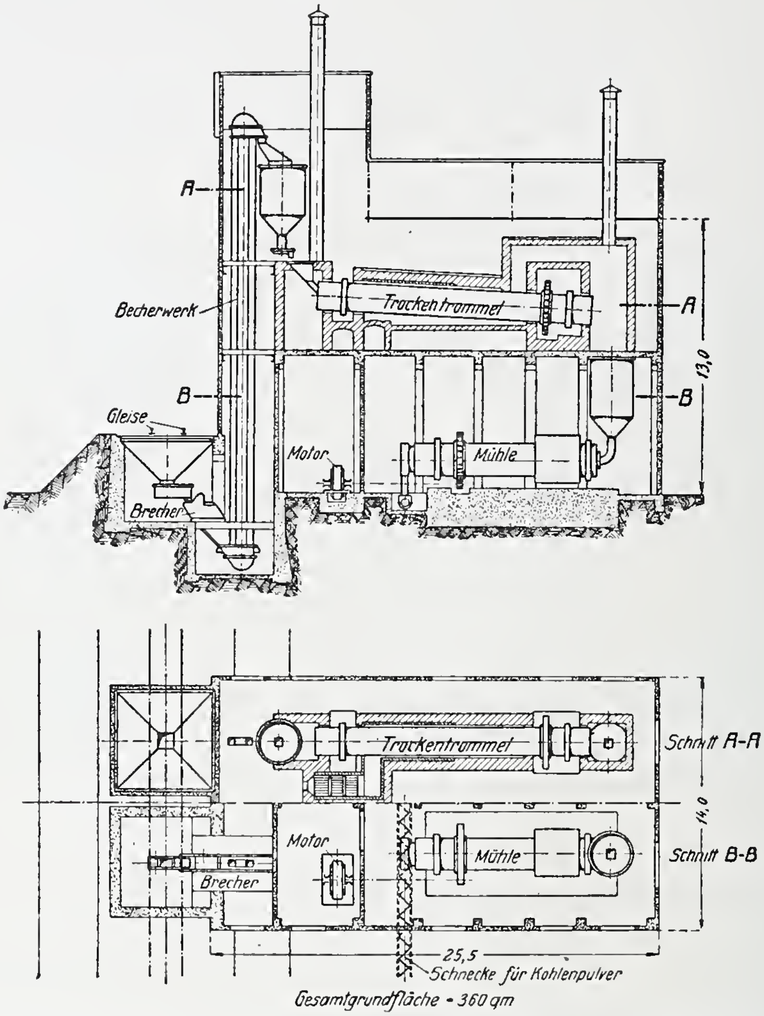


Fig. 65.—Arrangement of Solo Tube Mills with Rotary Coal Dryers above.
Dr. Ing. Friedrich Münzinger. Kohlenstaubfeuerungen für ortsfeste Dampfkessel.

This classification of material undergoing reduction, as well as of the grinding bodies, is illustrated in Fig. 66, which shows that in the largest diameter of the mill the incoming feed is crushed by the largest balls or pebbles, as the case may be, with the greatest height of fall and highest peripheral speed. As the discharge opening is approached, the crushing force is gradually diminished, as the grinding media are smaller and are dropped from a lesser height. The material undergoing reduction travels toward the discharge end as fast as it is reduced, thus allowing the full force of the heavy blows to fall upon the coarser particles behind without being

partly absorbed by fine material, as is the case when automatic segregation does not occur.

The Hardinge ball mill is designed to use forged-steel or cast-iron balls as grinding media, and the pebble mill to use flint pebbles or other similar grinding bodies. Both types are used for either wet or dry grinding. The general shape of the two types is the same, and they are built in nearly the same sizes. The construction differs to some extent because of the difference in character of the work which each is designed to perform.

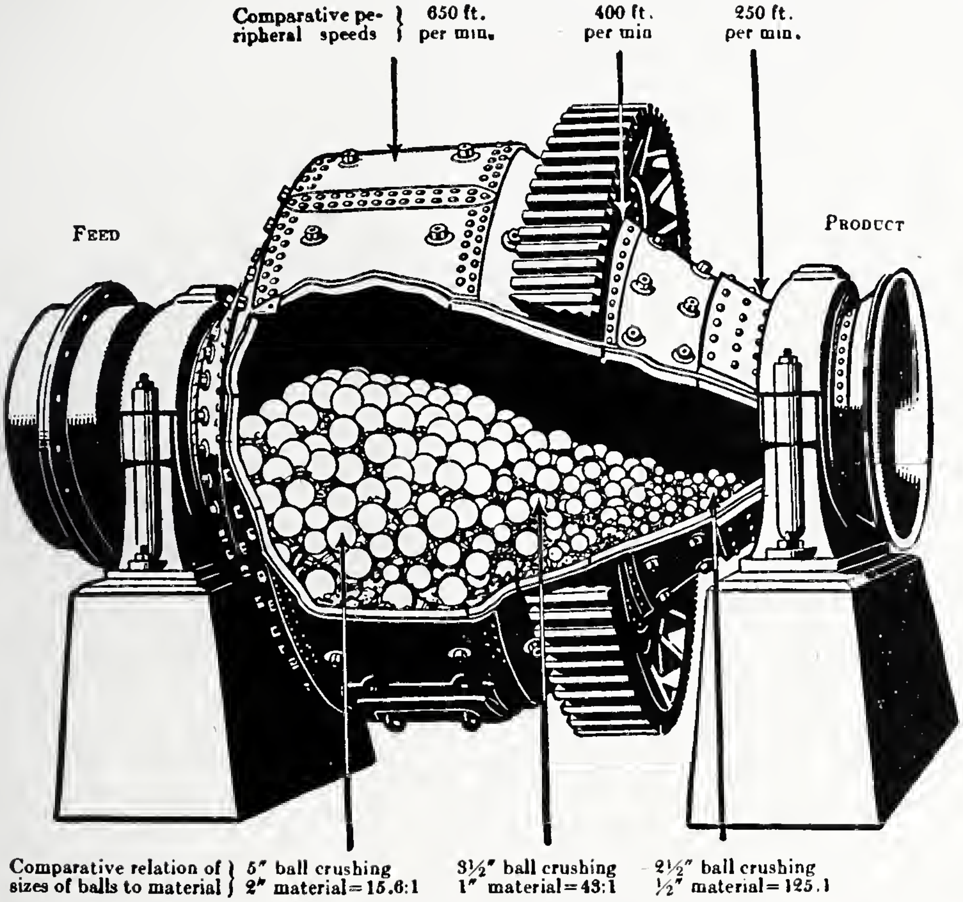


Fig. 66.—Section of "Hardinge" Ball Mill. (*The Hardinge Co.*)

The shell or drum consists of two plate-steel cones joined base to base with a short cylindrical wrapper piece, rolled, flanged, butt-strapped, riveted and caulked. The feed and diseharge trunnions are made of cast steel.

The lining consists of a combination of chilled charcoal-iron plates and alloy-steel wearing bars. This combination is considerably less expensive than an all-steel lining, and has a life well in excess of five years when the mill is used for grinding coal or coke dry. Either forged-steel or cast-iron balls are used as grinding media. In all cases the ball charge is designed to fit the actual work to be performed.

The ball mill being essentially a slow-speed machine—20 to 28 r.p.m. is a maximum

speed for the large sizes—has no complicated mechanisms, and, apart from the balls, has few wearing parts. There is practically nothing to get out of order. When properly set up and adjusted, it requires little attention, and should run for several years without requiring repairs, except for the addition of a few balls from time to time.

For fuel pulverisation the ball mill is used primarily where it is desired to grind from sizes up to 2 in. to the desired degree of fineness.

The advantages of conical tube mills are : (1) Power is saved, the energy being proportioned to the work performed. (2) The range of efficient grinding for a given size is large, owing to the segregation of the different sizes of grinding media

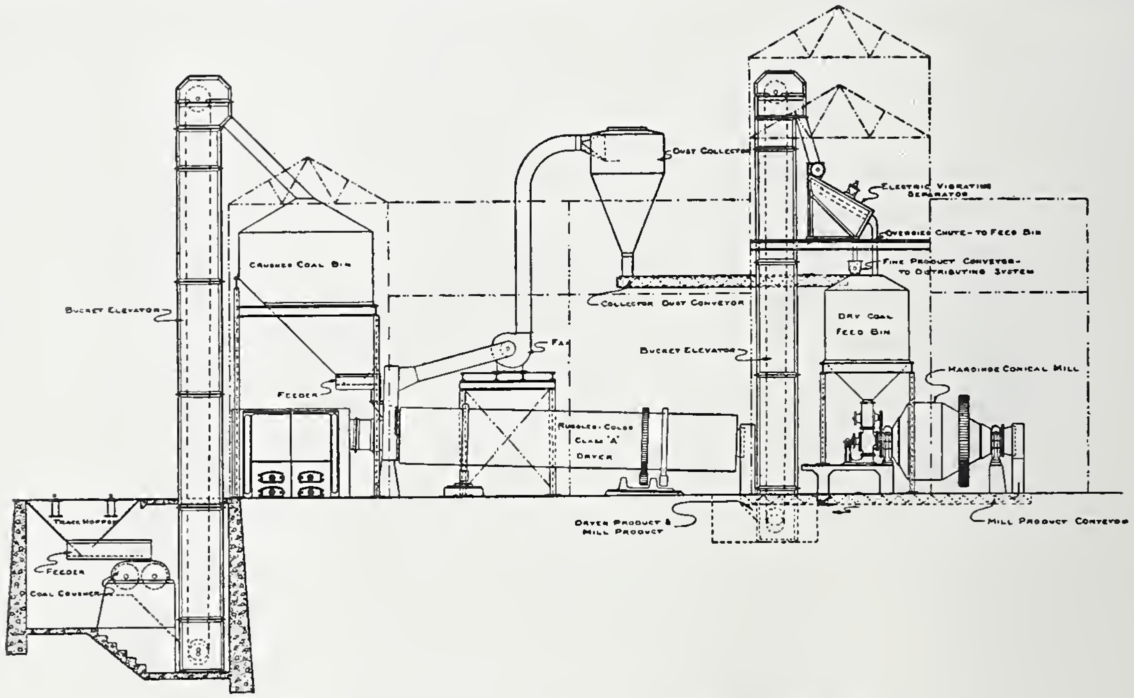


FIG. 67.—Typical Hardinge Mill Pulverised Fuel Plant.

and material. (3) The capacity for a given unit is large, owing to the rapid circulation of the ground material by the classifying action of the discharge cone. (4) The wear of both grinding media and lining is light, owing to the classifying action and circulation in the mill and the trunnion discharge. (5) The conical shape results in extreme rigidity and simplicity of construction, and mechanical troubles during operation are almost unknown. (6) The physical characteristics and fineness of the product can readily be varied, owing to the many different methods of controlling the operation of the conical mill. (7) The floor space and headroom required for a conical mill installation are unusually small, owing to the compact method of driving and the fact that the mill is self-contained. (8) Owing to the truss construction of the conical mill, a great weight of metal is not required to ensure sufficient strength. This lighter construction saves in the cost of transportation; also lighter foundations may be used. (9) The conical mill operates at

slow speed, has few moving and wearing parts, and requires relatively little lubrication. The number of parts subject to possible replacement are few and inexpensive. (10) The mill is water-tight when used for wet grinding and dust-tight when used for dry grinding. (11) Where large capacities are required, few conical mills need be used, as large capacity units are built, thus eliminating the necessity of a large battery of small units. (12) The use of magnetic separators to remove tramp iron from the feed is unnecessary. The admittance of such material to the mill will do no damage, in fact will actually aid in the grinding.

The arrangement of a typical pulverised-fuel plant designed by the Hardinge Co. for firing cement kilns, furnaces, boilers, etc., is substantially as indicated in Fig. 67. The absence of a magnetic separator not only reduces installation cost, but it also eliminates the necessity of supplying direct current, for which purpose a motor generator machine must be installed when alternating current only is available.

Attention is called in particular to the arrangement of the Hardinge mill and Hummer screen separator. This arrangement is particularly advantageous when the coal is in a fairly fine state as delivered from the dryer. Separation ahead of the mill increases the capacity of the unit, and also increases the grinding capacity of the pulveriser. When the electric separator is used with this arrangement, a two-surface screen is desirable, the first surface being a fairly coarse screen which removes coarse material and acts as a protector for the fine screen underneath. The two-surface screen increases the efficiency of operation as well as the life of the screen cloth. While the air separator saves, in some cases, the installation of another elevator, more power is required to operate the system than with equivalent electric separators.

To exhibit how easy it is to operate ball mills, it may be mentioned that in a mill-grinding material much harder than coal, there is in operation an installation of sixty-four Hardinge conical mills, 8 ft. in diameter, which are attended by only two men. Thus at this plant one attendant can supervise the running of thirty-two mills.

The above description of Hardinge mills has been taken from *Coal Age*, November 24, 1921, from an article upon the Lytle Colliery plant.

It is frequently recommended by makers that the linings of their ball or tube mills should be built up of flint. Ball and tube mills used for grinding coal are, however, usually fitted with sectionally built up lining plates of special cast iron chilled on the surface, and these will be found to last as long as flint linings. Sectional cast-iron linings, see Fig. 64, can be replaced within a day or so, whereas for refitting flint linings considerable care is necessary, and this operation may take several days to complete. For the grinding of coal, therefore, where contamination of the product with iron dust worn off from the surfaces of the iron plates does not really matter, it is advisable to use special iron linings, in order to keep down running costs and obtain maximum full running time.

The weight and surface of graded balls used are given in the following table:

Ball Table

Diameter of Ball.	Weight per Ball Pounds.	Weight per Ton (2000 lbs.).	Surface in Square Inches.
5″	20	100	78·54
$4\frac{1}{2}$″	13·50	148	63·62
4″	9·48	211	50·26
$3\frac{1}{2}$″	6·34	315	38·48
3″	3·96	505	28·27
$2\frac{1}{2}$″	2·31	860	19·64
2″	1·18	1690	12·57
$1\frac{1}{2}$″	·50	4010	7·07
$1\frac{1}{4}$″	·29	6230	4·91
$\frac{7}{8}$″	·10	20250	2·40

and an illustration of two 7 ft. mills grinding coal and discharging onto Hummer electric separator screens (see notes in next paragraphs) are shown in Fig. 72. Hummer screens arranged in this manner will separate pulverised fuel to a degree of fineness of 98 % through a 200-mesh screen. A diagrammatic view of a Hummer screen equipment is shown in Fig. 68. Hardinge mills fitted with air separation equipment are sometimes preferred. Arranged in this manner they are installed as shown in Fig. 70, and for discharge direct into a fuel elevator as shown in Fig. 71.

With a Hardinge Ball Mill, from which the pulverised product is delivered into a bucket elevator, and thence to a collector, a cyclone separator operated upon a somewhat different principle from that usually adopted is made use of.

The interior of this Gayco or Emeric separator is shown in Fig. 70*a*. In place of an external centrifugal exhaust fan, the pulverised fuel mill is delivered into the stationary feed pipe at the top of the separator, and falls on to the revolving distributing plate.

The hollow shaft, carrying the distributing plate and fan, is caused to rotate at a relatively slow speed (average 175 r.p.m.). Material is fed into the stationary feed pipe, and falling on the revolving distributing plate is thrown off in a thin sheet by centrifugal force. The revolving fan draws a current of air through this thin layer of material, carrying the material, fine enough to be lifted by the air current, into the fan chamber. The fine material is discharged by the fan against the inner wall of the outer casing, sliding down the same to the outlet in the bottom. The air circulates downward between the inner and outer casings, and enters the inner casing through the opening between the inner casing and the lower cone, again passing through the material as it falls off the lower edge of the inner casing in the form of a circular curtain, removing any fine particles which were not taken out when the material was first spread by the distributing plate. The volume of air in circulation is controlled by an adjustable damper or valve, which regulates the fineness of the product. The area of the openings, direction of the air currents, and the deflecting arrangement of the parts, are such that the fine material is removed from the air and settles to the bottom of the outer casing, and is discharged through the outlet provided, while the coarse material falls into the lower inner cone, and passes out through the tailings spout.

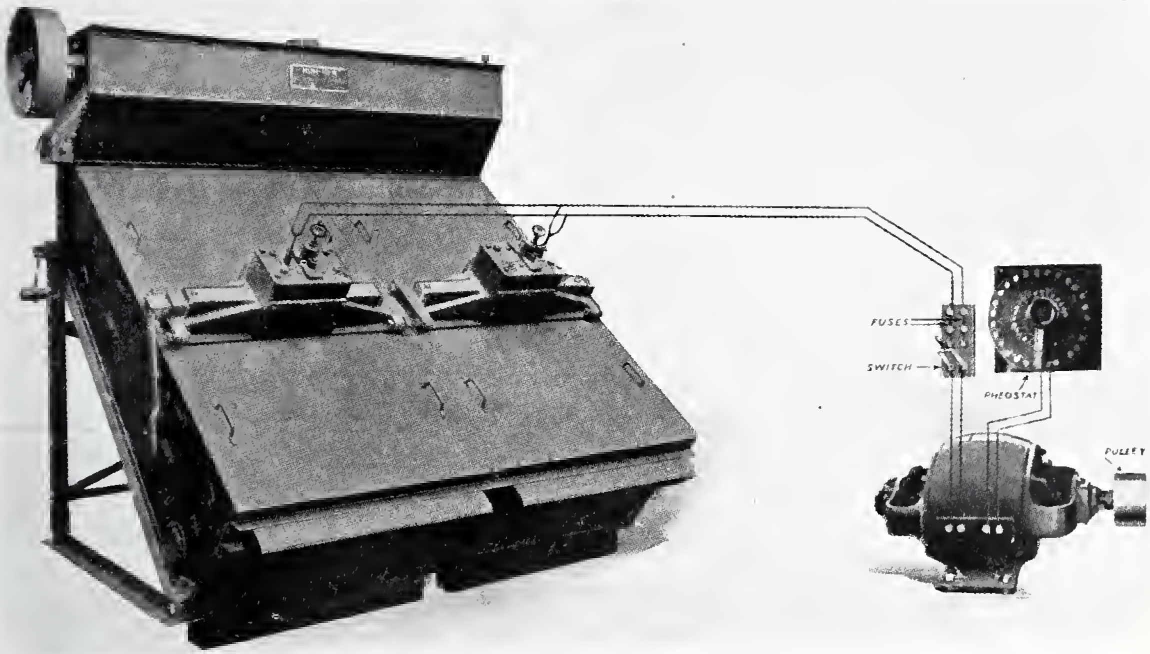


FIG. 68.—HUMMER ELECTRIC VIBRATOR SCREEN, SHOWING MOTOR GENERATOR AND WIRING.

W. S. Tyler Co.]

[*To face p.* 178.

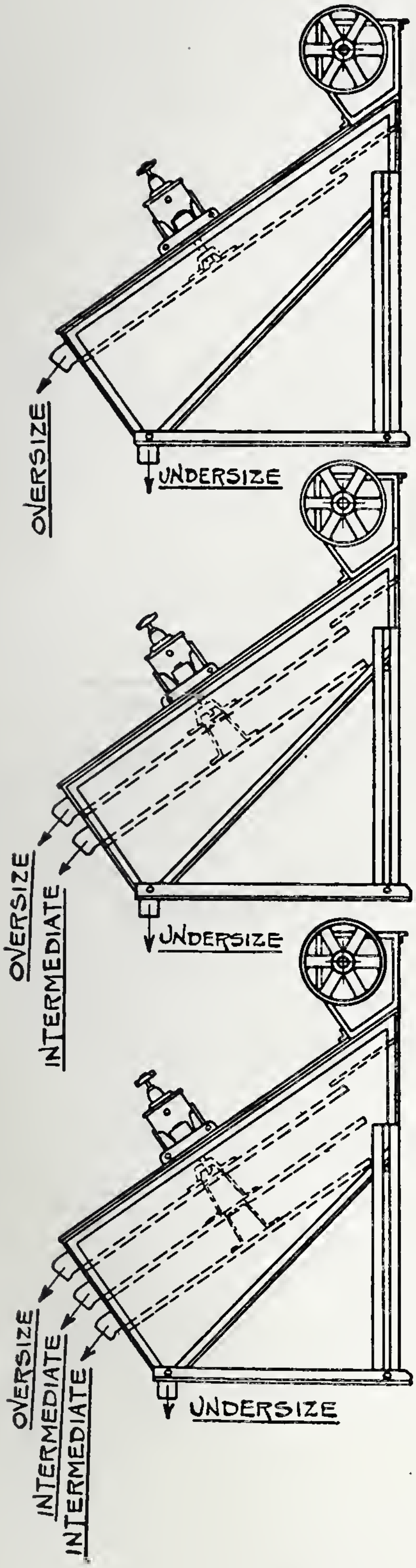


Fig. 69.—Hummer Electric Vibrator Screens, showing single, double and treble Screening. (*The Hardinge Co.*).

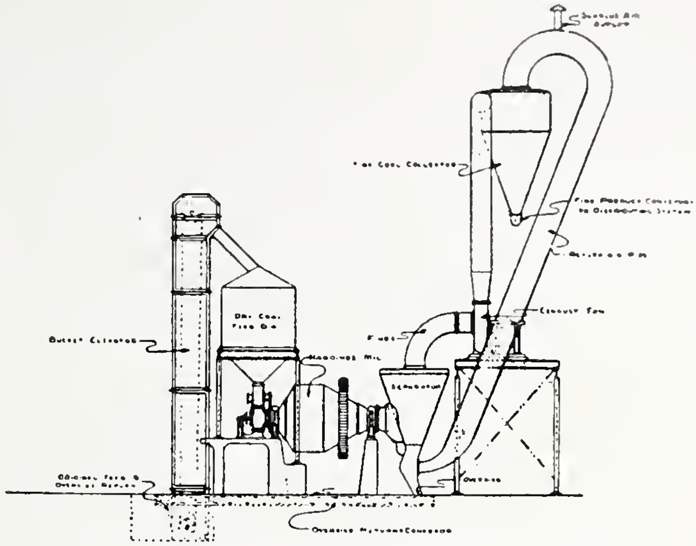


Fig. 70.—Hardinge Ball Mill arranged for Air Separation. (*The Hardinge Co.*)

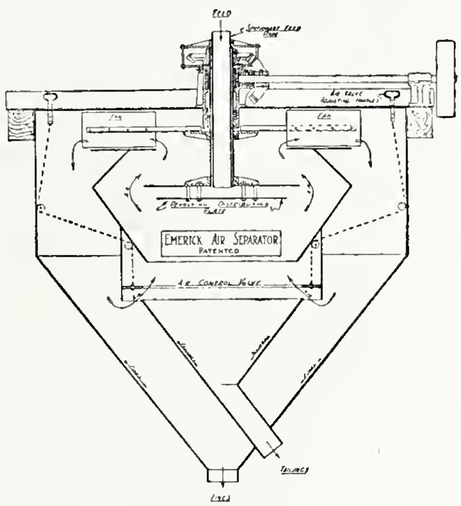


Fig. 70*a*.—The Emeric or "Gayco" Separator. (*Rupert M. Gay Co., U.S.A.*)

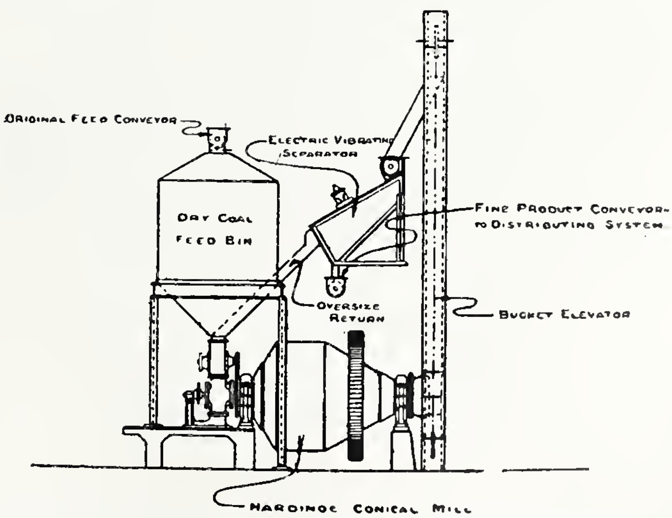


Fig. 71.—Hardinge Ball Mill working in closed circuit with Elevator and Hummer Screen. (*The Hardinge Co.*)

Electrically Vibrated Separate Screens.

The perfecting of the electrically vibrated screen has greatly increased the advantage of the ball or tube mill, the output from which types of mills has in the past been somewhat restricted, owing to the necessity of retaining the fuel in the mill until the degree of fineness of the bulk, if not of all the particles, has been reached.

Discharge from such mills can now be considerably increased when vibrator screens are employed, the coarse oversize being returned to the feed end of the mill.

Further illustrations of the Hummer electric screens are shown in Figs. 73 and 74. Fig. 73 shows an equipment with one cover plate removed, disclosing the screen. Fig. 74 shows the electro-magnet and the centre pillar which is attached to the centre of the screen. By means of the hand wheel seen above the magnet box, the intensity of the vibration can be varied to suit the material to be screened.

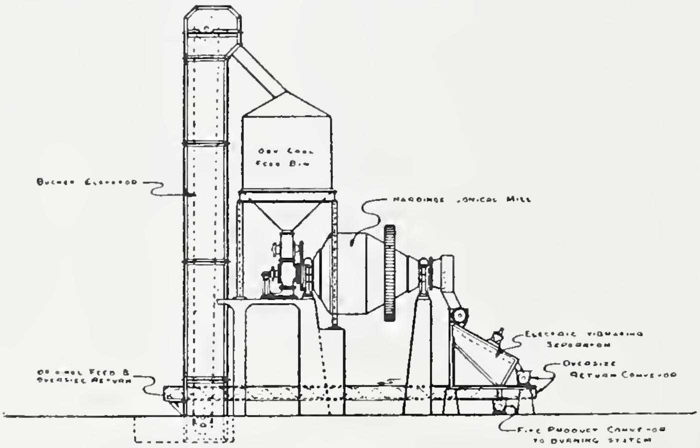


Fig. 72.—Hardinge Ball Mill discharging into Hummer Screen, reject returned to Elevator. (*The Hardinge Co.*)

The upward pull of the screen cloth takes place at great speed and, as the material travels down the screen, the larger particles are forced to the top, allowing the fine material to hug the screen, giving it every opportunity to pass through the meshes.

The Hummer vibrator can be supplied with one, two or three screens, all operated by the one vibrator. Arranged in this manner, the screens are shown in Fig. 69, the two-screen equipment being that generally used in connection with pulverised fuel grading.

If it is desired that the fine dust be extracted by air suction, a rotary fan is installed, and the product extracted from the screen frame and delivered into a cyclone separator, as shown in Fig. 76.

The electro magnets are designed to operate with alternating current 110 volts, 15 cycles, and small motor generator units, which can be driven from line shafting, are supplied to suit the number and size of screens installed.

In Fig. 78 there is shown the discharge end of a rotary dryer delivering dried coal direct into a Hardinge ball mill running on closed circuit, the pulverised fuel as discharged from the mill being syphoned up to the cyclone separator. From this point the fuel is discharged onto a Hummer screen, the undersize passing into the hopper for feeding to the burner, and the oversize being rejected through the chute and passed again through the mill. This illustration indicates a small capacity compact pulverised-coal plant as recommended by the Quigley Co.

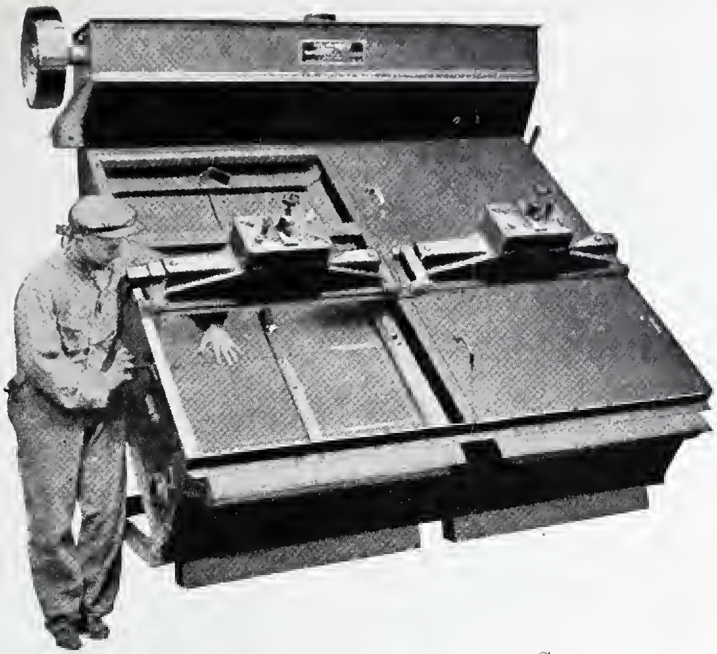


FIG. 73.—HUMMER ELECTRIC VIBRATOR SCREEN WITH COVER PLATE REMOVED.

W. S. Tyler Co.]

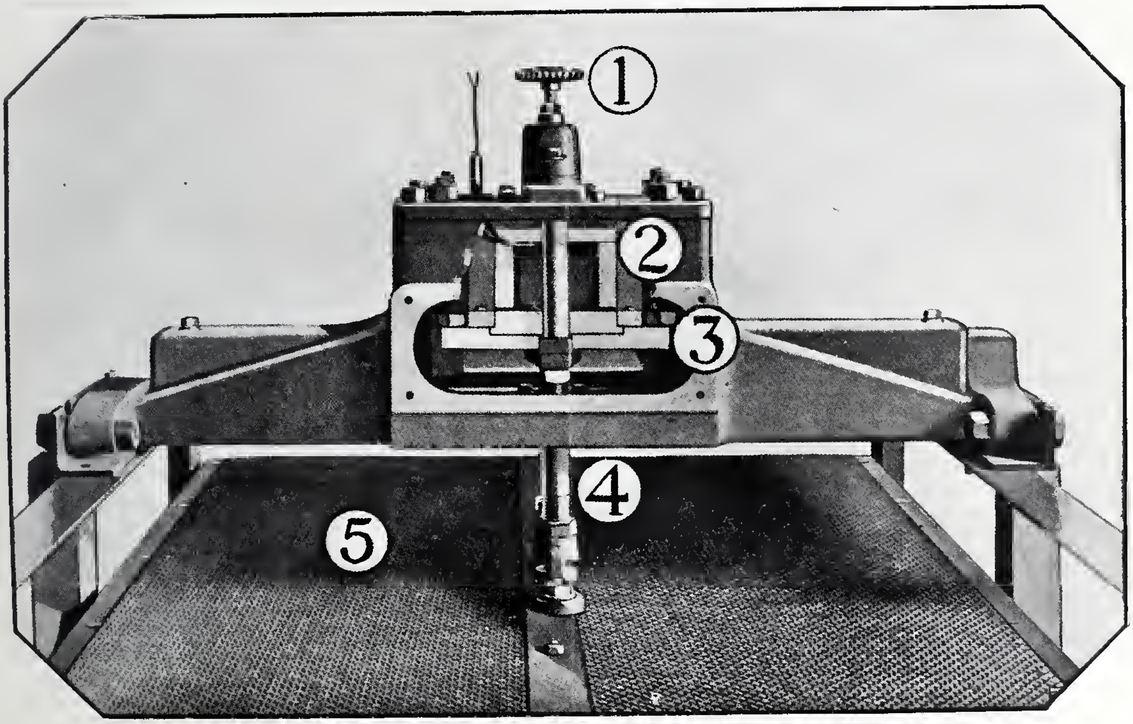


FIG. 74.—HUMMER ELECTRIC VIBRATOR SCREEN

1. Hand-wheel for regulating Intensity. 2. Vibration Coil and Magnet. 3. Armature. 4. Armature Post and Bracket. 5. Wire Cloth at Drumhead tension, coupled to Armature Bracket.

W. S. Tyler Co.]

[*To face p.* 180.

FIG. 75.—FULLER AIR SEPARATOR PULVERISER MILLS, SHOWING ENCLOSED DRIVE, COAL BUNKERS, AND AIR SEPARATOR PIPING.

The Fuller Engineering Co.] [*The Fuller Lehigh Co.*

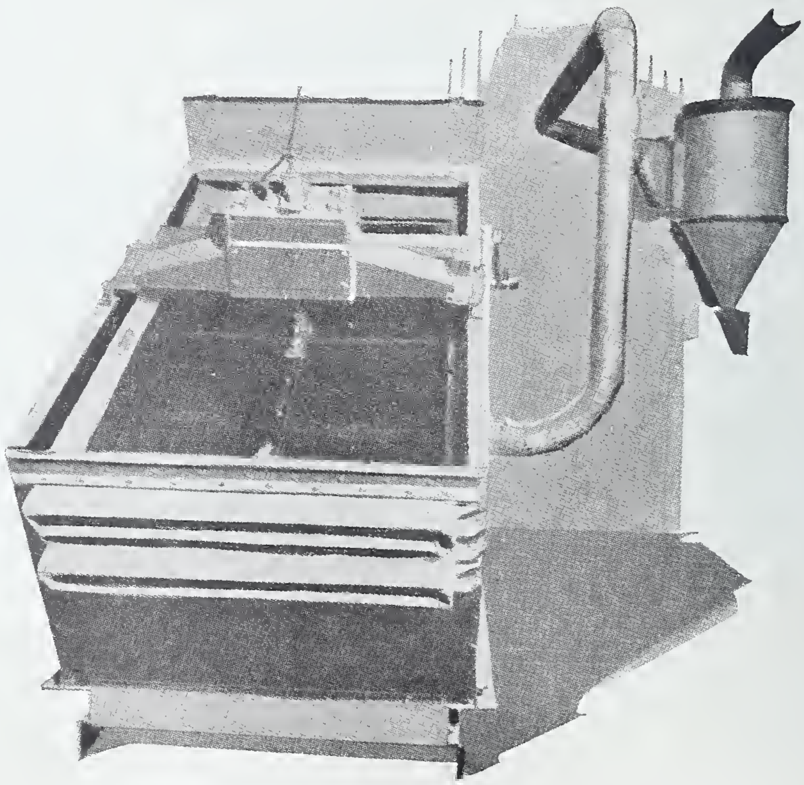


FIG. 76.—HUMMER VIBRATOR SCREEN ARRANGED FOR AIR SEPARATION.

W. S. Tyler Co.]

Fig. 79 shows one of the 10 ft. diameter Hardinge mills, the largest size made, as a unit in a pulverised coal plant.

Screen v. Air Separator Mills.

Turning now to American practice, one finds that the relatively high-speed (100 to 150 r.p.m.) swing pendulum or ball and pusher types of mills are almost universally installed in pulverised-coal plants, at all events, so far as pulverised-coal plants for metallurgical smelting and heating, and for steam raising boilers, are concerned.

The two types of outstanding merit which have been generally adopted in America are, screen-separator mills, such as the Fuller mill shown in Fig. 80, and air-separator mills, such as the Raymond mill shown in Fig. 81. In making comparison between screen-separator mills and air-separator mills, it is necessary to consider the power absorbed for separating out and delivery of the fine coal powder, in addition to the actual power taken for grinding the coal.

A screen mill having a capacity of, say, 4 tons of product per hour, and allowing 5 h.p. for operating the pulverised-coal elevator, requires about 65 h.p. An air-separator mill rated at the same capacity would absorb (with air-separator fan) about 100 h.p., the amount of power depending upon the location of the suction fan and the dust collector with respect to the mill. An air-separator mill of this capacity is generally run in conjunction with a suction fan having a wheel of, say, 42 in. diameter and run at a speed of approximately 1150 r.p.m. The speed of the fan is, naturally, a variable factor depending on the specific gravity of the coal, the fineness of finished product desired, the quantity of coal to be obtained per hour, and the relative position of the mill in respect to the position of the dust collector. It is sometimes necessary to operate this fan at a speed of from 1250

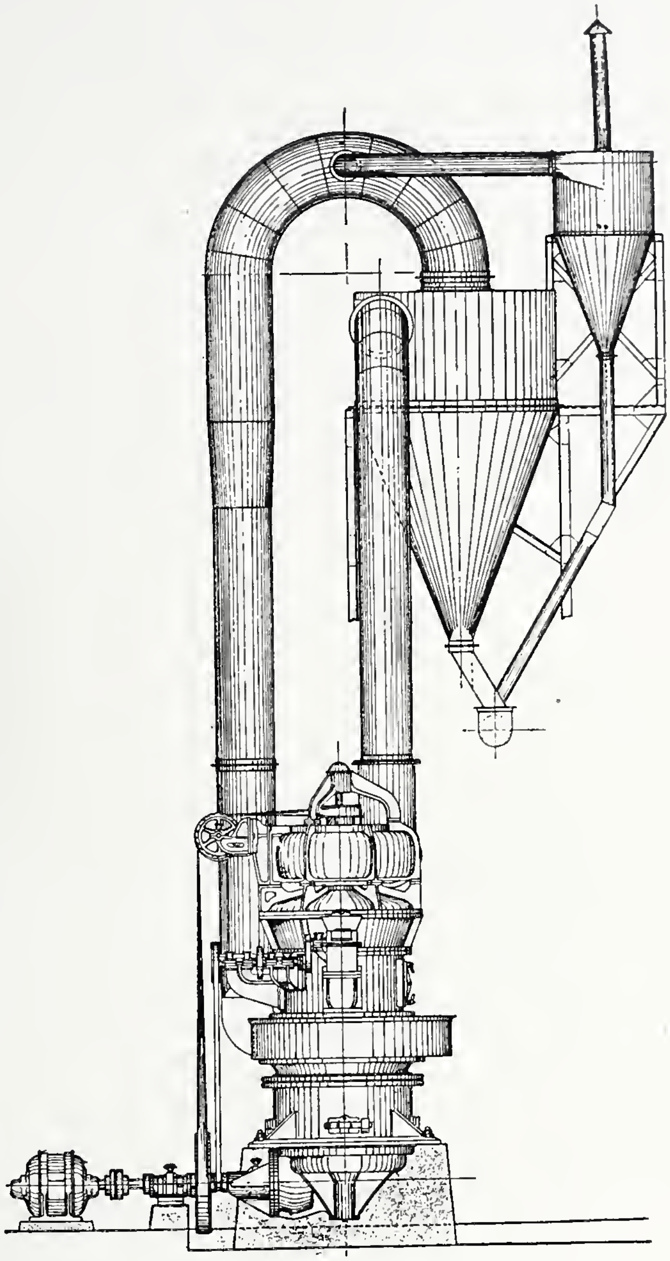


Fig. 77.—Fuller Air-Separator Mill and Cyclone Separators.

to 1350 r.p.m., but for a comparative study a speed of 1150 r.p.m. will be assured.

In order to lift 4 tons of coal per hour, pulverised to a fineness of 96 % through a 100-mesh sieve, and 80 % to 82 % through a 200-mesh sieve, from the pulverising zone of an air-separator mill, it is necessary to handle from 17,000 to 18,000 cu. ft. of air per minute at a pressure of six ounces per sq. in. A 42 in. fan wheel, operating at a speed of 1150 r.p.m., will deal with this 18,000 cu. ft. of air per minute at the pressure stated. The power required to move this quantity of air, surcharged with dust, depends upon the velocity of the air, the area of the delivery piping, bend friction, etc., and can be roughly calculated by multiplying the velocity of the air in feet per minute by the theoretical discharge area of the fan in sq. in., and by the pressure of the air in lb. per sq. in. The figures obtained must be divided by 33,000 in order to obtain the theoretical horse power required. In the case under consideration it will be found that it requires about 36·5 h.p. to move the quantity of air, surcharged with coal-dust, to the extent of 4 tons of coal-dust per hour. In other words, in addition to the power required to pulverise the coal, it is necessary with an air separator mill to provide 36·5 h.p. additional to lift this coal from the pulverising zone and deliver it to a cyclone separator, say, 30 ft. maximum lift above the mill.

In the case of a screen separator mill, a 5 h.p. motor will operate the necessary bucket elevator or, say, an addition of less than 10 % of the power taken by the mill for grinding, whereas with the air separator mill at least 36 h.p. is absorbed in the delivery of the product to the cyclone separator, an addition of upwards of 50 % of the power actually taken by the mill for grinding the coal.

Therefore for equal output of coal-dust, 25 % to 50 % additional power is necessary to operate pulverising mills and the individual air-separator fuel delivery fans.

These suction fans for air separation must be run at high velocity, 1000 to 1250 revolutions per minute, the speed depending upon the fineness required, upon the quantity of coal per hour, and upon the positions of fans in relation to cyclone separators, etc. At this high speed the fan wheels are called upon to carry a very heavy strain. The wearing effect of coal-dust on the fan blades, or the reinforcing manganese steel plates, may require their frequent renewal.

The fan blades shown in Fig. 82, directly attached to the yoke of a screen-separator mill, such as the Fuller Mill, for the purpose of driving the fine fuel through the screens, absorb about 1 % of the power taken by the mill. For air separation the power taken by the exhausting fan may be 35 or 40 % of the power actually used for pulverising, and for a screen mill with bucket elevator the power taken for fan and elevator is under 10 % of the mill power.

In an actual test carried out on an air-separator mill pulverising 4·65 tons dry bituminous coal per hour, the normal power absorbed for mill and exhauster fan was 97·68 h.p. or 15·45 h.p. per ton dry coal pulverised and delivered to cyclone separator 30 ft. above the mill. The moisture content of coal delivered to the mill was 5·18 %, and the fineness of the pulverised coal showed 96·7 % through a 100-mesh and 79·3 % through a 200-mesh screen.

As against the increased power required for delivery of the product to the storage

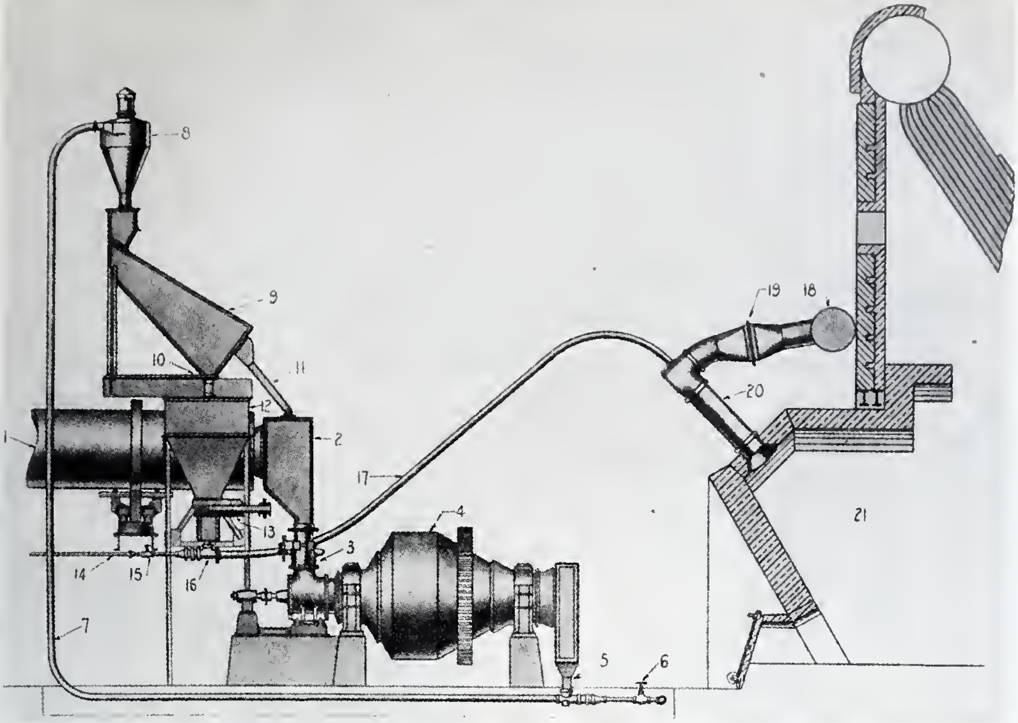


Fig. 78.—Rotary Dryer discharging direct into Hardinge Ball Mill.

1. Dryer.
2. Dryer Discharge Hopper.
3. Pulveriser Feeder.
4. Pulveriser-Hardinge Conical Mill.
5. Inlet to Pneumatic Elevator.
6. Pneumatic Elevator Control.
7. Pneumatic Elevator Pipe.
8. Elevator Collector.
9. Electrically Vibrated Screen.
10. Fine Product Discharge.
11. Over-size Return to Pulveriser.
12. Powdered Fuel Hopper.
13. Dust-tight Gate.
14. Air Line.
15. Valve Controlling Fuel Supply.
16. Pneumatic Feeder.
17. Powdered Fuel Feed Pipe.
18. Combustion Air Main.
19. Grid Type Blast Gate.
20. Powdered Fuel Burner.
21. Combustion Chamber.

Quigley Fuel Systems, Inc.] [*The Hardinge Co.*

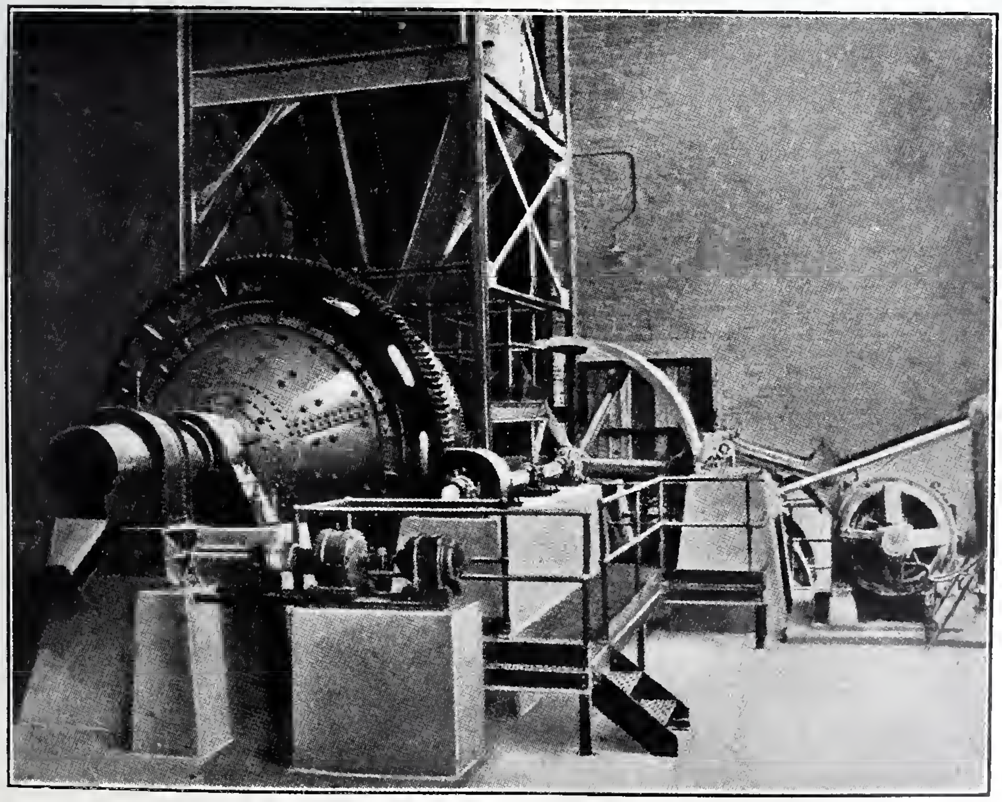


Fig. 79.—Hardinge Ball Mill (10 ft. diameter).

The Hardinge Co. [*To face p.* 182.

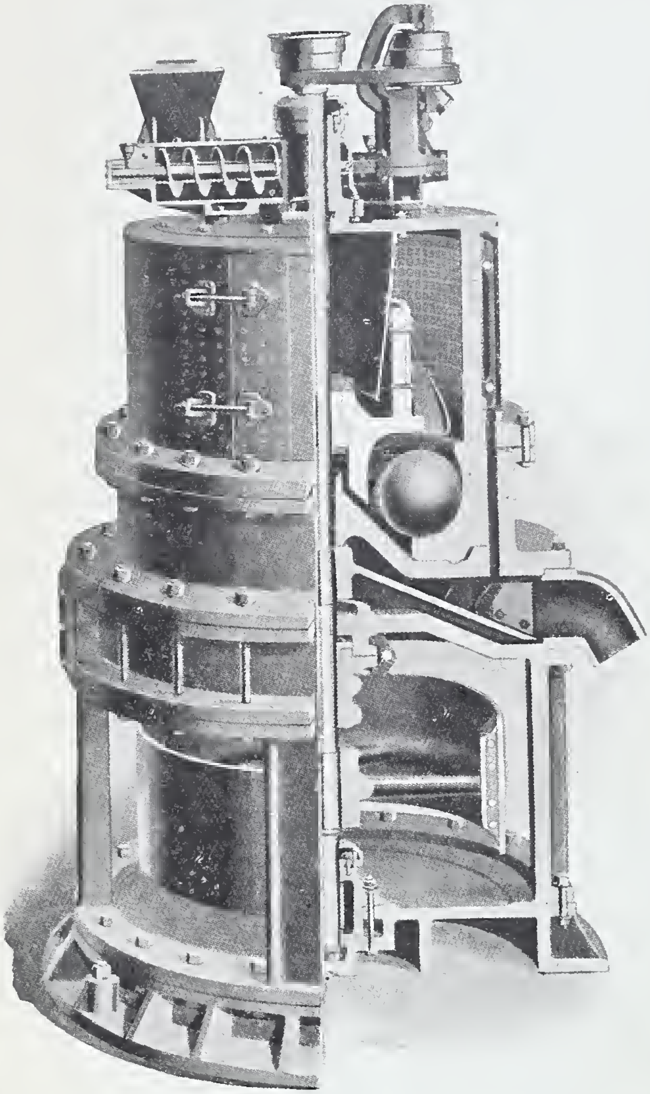


FIG. 80.—FULLER LEHIGH SCREEN SEPARATOR MILL.

The Fuller Lehigh Co.]

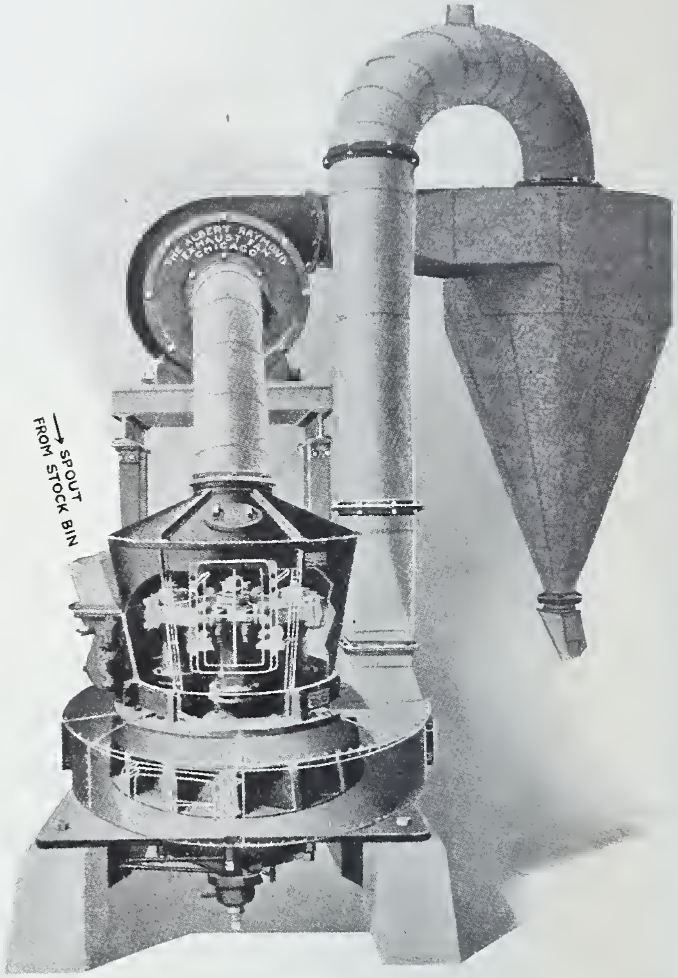


FIG. 81.—RAYMOND PULVERISER MILL, SHOWING AIR SEPARATOR FAN AND FUEL COLLECTOR.

Raymond Brothers Impact Pulveriser Co.]

bin, the air separation system has the great advantage of cleaner working conditions in all circumstances, and the absence of a chain and bucket elevators, fuel pumping systems, or screen conveyors, which are perhaps liable to total breakdown more frequently than a rotary suction fan.

A screen mill is usually fitted with an internal discharge fan built integral with the mill, and operating at a low speed in the region of 160 r.p.m. The fan usually handles about 900 to 1000 cu. ft. of air per minute at a pressure of one-quarter of an ounce per sq. in., thus adding only about 1 h.p. to the power required for grinding.

In all the earlier installations of screen mills, the raw coal and coal-dust in the mill-house was removed by means of bucket elevators. Later developments have established the success of the Fuller-Kinyon pumping system in place of the pulverised-coal elevator and screw conveyor. This fuel pump is referred to at p. 220.

It is quite an open question which system should be adopted, and many factors must be considered in each particular case. It will be noticed that air separation has been adopted for the Milwaukee Super Power Station plant, yet for another modern plant screen-separator mills have again been preferred.

A screen mill undoubtedly produces a greater proportion of very fine powder, generally termed "impalpable powder," which is of value in effecting the early ignition and ready combustion of pulverised coal, and, on the whole, the product from a screen-separator mill may be the more uniform, providing the mill screens do not become damaged.

For all practical purposes, and so far as actual product is concerned, the screen or air-separation type of mill can be used with equally good results.

It may be contended that screen-separator mill-houses can be very dirty. This the author knows from observation, but certain air-separator mill-houses which he has inspected were in no cleaner condition. Given intelligent and interested supervision, there is no necessity to have dusty or dirty conditions with modern, well-designed screen-separator mills, especially when a pumping system is installed to draw the pulverised coal from the mill discharge and deliver it into the storage bins.

Wear and Tear of High Speed Mills.

All parts inside a ball and pusher mill are plain forgings and castings, whereas roller and ring mills must have many machined parts which, on becoming worn, are no longer "machine fit," and are, therefore, working under non-mechanical conditions. At best, all pulverising mills must be of somewhat crude mechanical construction, and the less machining of parts in the pulverising zone the better.

In course of time the efficiency of any mill will fail owing to the wearing away and, therefore, to the loss of weight of grinding elements, and to the alteration in shape of the latter; and, in the case of screen mills, the fineness will fall away when the screens become worn or damaged.

Although the finished product from mills fitted with screens is of the standard degree of fineness, viz. 85 % through a 200-mesh screen, the screens actually fitted inside the mills are not, of course, anything approaching this mesh. No coal would ever go through them.

Screen mills are provided with coarse, strong protecting grids with ½ in. or 1 in. openings, and behind these cylinders are placed the finishing screens, as shown in Fig. 80. The latter are usually of steel wire of 35 to 45 mesh. The fine pulverised fuel is fanned through the finishing screens, the stream of fuel passing through the holes tangentially. A fraction only of the full opening of each hole in the screen is presented to the free flow of coal dust. The degree of fineness is governed by the speed of rotation, dryness of the coal, and setting of the fan blades.

The pins securing pushers or rollers to the rotating members of mills should be carefully examined from time to time for wear and fatigue. If made of steel, the constant jarring may well produce crystallisation, and the pins will break. To overcome fatigue, it is advocated that such pins should be forged out of soft iron, as this metal remains tough, and when worn can be reforged to shape, reheaded and used again, the heating process restoring the metal to its original strength.

There is perhaps a greater element of uncertainty as to length of service of the actual grinding ring than in the case of any other part of a mill. The grinding ring is essentially of massive section, and is usually made of special cast iron, hardened or chilled on the grinding surface to a depth of upwards of 0·5 in. It matters little whether surface cracks develop in the chilled surface, so long as these do not form small isolated sections of metal which may break away when the mill is started, especially if the mill is at first run empty. Considerable damage may occur if a mill is allowed to run empty for any length of time. When starting up, coal must be fed into the mill at the very earliest moment, and when stopping, it is better practice to allow some coal to remain unpulverised and to clear this from the mill after shutting down.

On the question of upkeep of rotary grinding mills, the following list will give an idea as to the normal life of parts for a 5 ton per hour Fuller Mill. These figures can be accepted as good practice for mills of this type when running on bituminous coal and operating 10 hours per day.

Description of Part.	Average Normal Life Approximately.
Grinding Ring	12 months
,, Balls (4)	6 ,,
,, Pushers (4)	4 ,,
Pusher Pins (4)	4 ,,
Yoke Support	12 ,,
Complete Yoke	12 ,,
Coal Spud	4 ,,
Vertical Shaft Step Block	4 ,,
Finishing Screens (1 set)	3 ,,
Protecting Screens (1 set)	12 ,,
Vertical Shaft Top Bearing Bush	4 ,,
,, ,, Lower Bearing Bush	4 ,,
,, ,, Intermediate Bush	4 ,,
Feed Gear Bushings (1 set)	3 ,,
Coal Feed Screw	4 ,,
,, ,, (Gear Wheel)	6 ,,
,, ,, (Pinion)	6 ,,

Quantity of Lubricant		
	Top Bearing.	5 lb. grease per week.
	Intermediate Bearing.	,, ,, ,,
	Bottom Bearing.	1 quart oil per week.

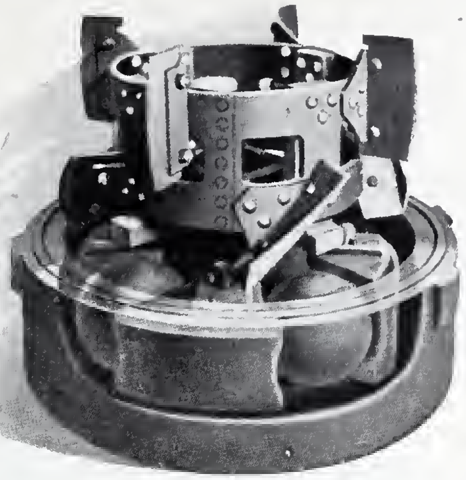


Fig. 82.—Grinding and Separating Elements of Fuller Lehigh Pulveriser Mill.

The Fuller Lehigh Co.]

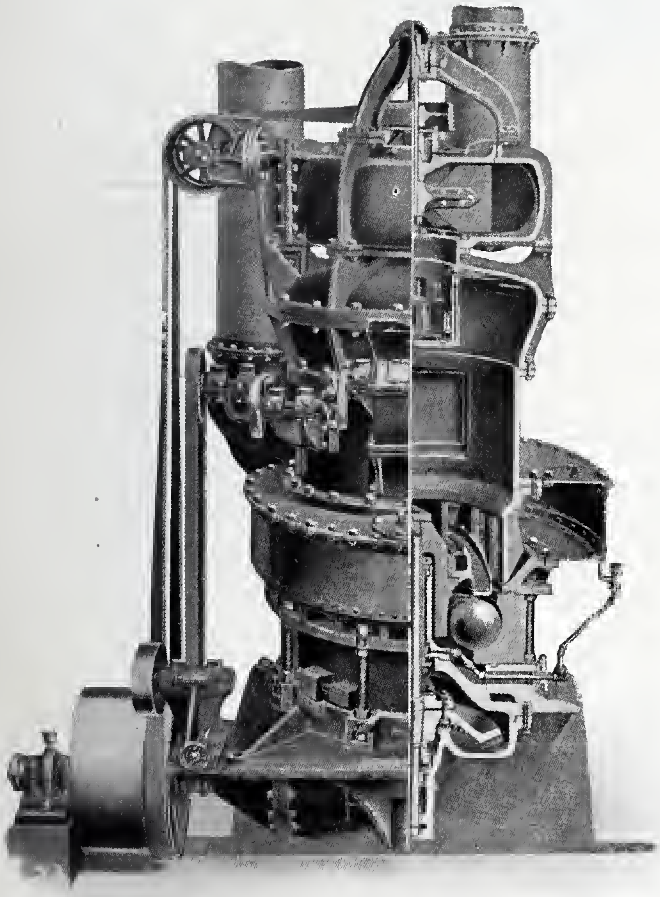


Fig. 83.—Fuller Air Separator Type Pulveriser Mill.

The Fuller Engineering Co.] [*The Fuller Lehigh Co.*

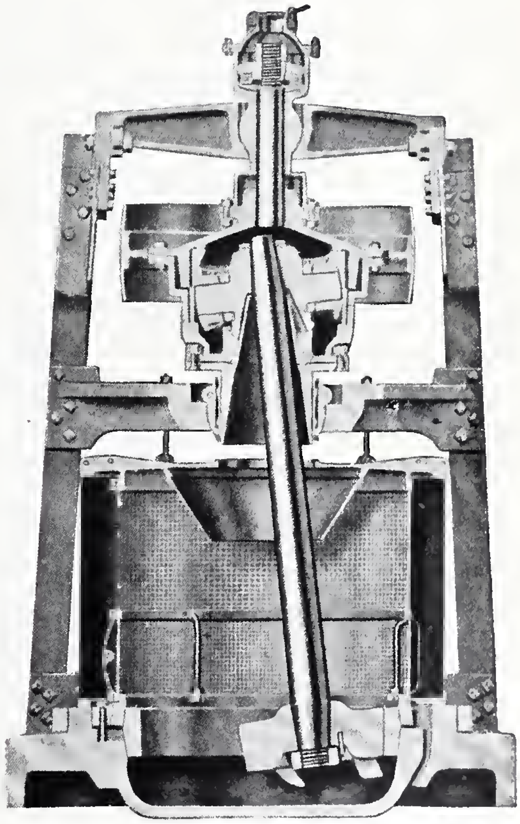


Fig. 84.—Improved Giant Swing Roller Griffin Pulveriser Mill.

The Bradley Pulveriser Co.]

[*To face p.* 184.

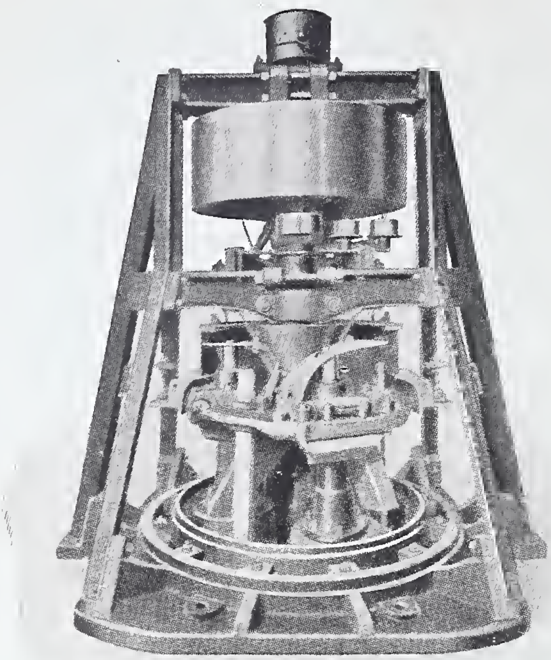


FIG. 85.—BRADLEY 3-ROLL PULVERISER MILL.

The Bradley Pulveriser Co.]

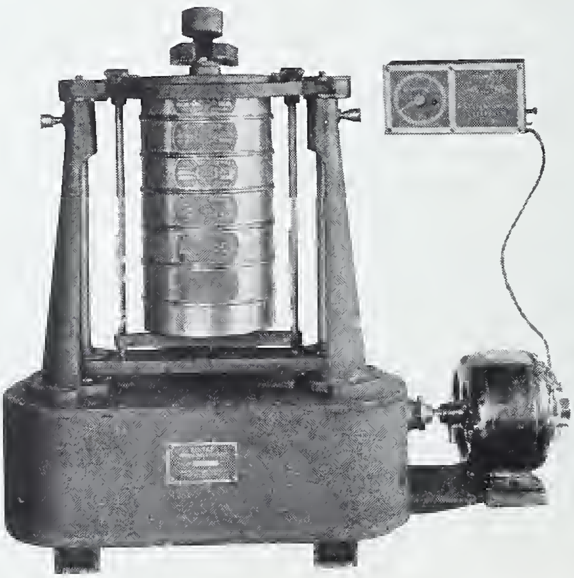


FIG. 86.—THE RO-TAP PULVERISED FUEL TESTING MACHINE.

W. S. Tyler Co.]

Pulverised Anthracite Coal and Coke.

Pulverised coke has been burnt in furnaces with the same facility as anthracite coal; there is, naturally, more wear upon mill parts when employed on these materials than when a mill is operating on softer fuel.

As a broad statement it can be accepted that when pulverising anthracite coal the wear upon mill parts will be increased, over bituminous coal figures, by 25% to 50%, and mill output be reduced by 30% to 40% for equal power input, this depending upon the degree of hardness of the anthracite coal. When pulverising coke of, say, 10% to 15% volatile matter and 10% to 15% ash content (the product of City Gas Works distillation plants and not metallurgical hard coke) the wear of mill parts will be increased by 100%, and mill output reduced by approximately 50%.

The increased wear when grinding coke is attributable as much, and perhaps more, to the ash than to the degree of hardness of the coke, the ash introducing specially abrasive qualities. For high ash (30%) low-volatile (5%) coke, the cost of mill upkeep may be as high as four times that for bituminous coal.

In connection with the preparation of pulverised coke, the main additional cost is, therefore, in the maintenance of the wearing parts of the mill, and in the power required for any given output. The costs of power and maintenance for other portions of a standard mill-house plant will remain appreciably the same as when pulverising bituminous coal.

In the more usual types of air-separator mills, as, for instance, the Raymond mill, Fig. 81, the air freed in the cyclone separators is returned to the mill below the grinding zone, so that this air has to pass up through the coal in course of pulverisation. In other types of mills, as in the Fuller air-separator mill, Fig. 83, the return air re-enters the mill at a point above the actual grinding zone, and so has not to be drawn through the coal under pulverisation. When the latter is the case, the power taken by the extraction fan is considerably less than that required when the air has to circulate through the fuel in the mill.

The single roller type of mill, the Griffin mill shown in Fig. 84, and another multiple roller, the Bradley mill shown in Fig. 85, have been extensively used. Centrifugal action brings the rollers in contact with the stationary grinding ring, the coal being reduced to a fine powder between the rollers and the ring.

The possibility of journal bolts or nuts working loose and falling into the mill is not of any great moment, and is not very often realised in present-day mills. If pieces of iron or steel nuts find their way into the mill with the coal, and become red hot through continuous pounding in the pulverising zone, they may ignite the fuel and, when conditions are suitable, cause an explosion. Some accidents in the past have been attributed to this cause. The remedy is to use only mills of sound rugged construction, with efficient magnetie separators which should remove all pieces of iron in the erushed coal before this is fed into the mills.

The chief difficulties in connection with interior roller bearings are those of rapid wear of bearing surfaces and lubrication. In actual practice, when bearings become worn, consumption of lubricating oil or grease increases very considerably, this being more particularly the case with mills fitted with internal journals and roller

bearings which have to run in contact with the dust in the pulverising zone. For this reason, the amount of lubricant used on the latter type of mill may well be several times the amount required for a mill fitted with external bearings.

Another point to remember is that mills fitted with bearings inside the pulverising zone often have to be stopped every few hours, so that the journals or moving parts can be re-lubricated. Mills having external bearings can be run continuously without stopping for this purpose. In one case a mill of this type used up 100 lb. of grease per day, whereas a mill having external bearings used but 20 lb. of grease per day, but the former type of mill, when new or with bearings correctly fitted, would require no more than the 20 lb. of grease.

Fuel Feed to Mills and Testing for Fineness.

One would think on first consideration that output from a pulveriser mill would be increased when fed with fine coal. This is not so. In practice it is found that the best output is obtainable when crushed coal is ground, the larger lumps of coal presumably tending to displace the rollers or balls from the grinding ring, thereby mixing the fuel in the grinding zone, presenting new material between the grinding faces, and adding increased impetus to the rollers or balls in their movement outwards against the grinding rim, due to centrifugal force. When fine coal is fed into a mill a smooth cushion is formed on the face of the grinding ring, and in the absence of lumps this cushion is not so readily disturbed.

It is sometimes asked whether the coal from the dryer may be so hot that its introduction into the pulveriser mills would be dangerous. There appears to be little danger from this source, especially when a screen separator type of mill is used. Hot burning coal has been fed for considerable periods into screen mills, wherein the action of the pulverising balls and the small quantity of air present in comparison with the mass of lump coal and coal-dust has had the effect of smothering the burning coal. With air separation there might be produced an explosive mixture which could become ignited.

In any large plant at which a number of pulverising mills are in service, each contributing to the general supply of pulverised fuel, it is essential to ascertain with sufficient frequency that the requisite degree of fineness is being obtained. Coarse fuel in the main supply will be no guide as to which mill or mills are not operating up to standard requirements.

A sample should be taken at the outlet of each mill from time to time—this is the more necessary with screen mills in which screens may have become pierced—and each sample should be examined for fineness. To do this by hand would be laborious, and some mechanical testing apparatus should be used with which quick tests can be made.

To this end the W. S. Tyler Company's Ro-Tap Testing Sieve Shaker has been designed and constructed to facilitate the making of continuous tests of fine products such as cement and pulverised coal. Fig. 86 shows this apparatus fitted with a nest of testing sieves and an electric motor. After placing the sample in the top sieve and arranging in the manner shown, the motor is started and the Ro-Tap Testing Sieve Shaker then reproduces the circular and tapping motion given to

testing sieves in hand sieving, but with a uniform, mechanical action, producing dependable sizing tests.

The economy is not only in the big saving of time and labour, and in the longer "life" of the testing sieves, but there is a saving by eliminating errors in testing.

As a means of running such tests for a given period this Company supplies the "Stop-Rite" Time Switch shown in the illustration.

W. S. Tyler Company Standard Screen Scale Sieves.

Opening in Inches Ratio or 1·414.	Opening in Millimetres.	Opening in Fraction of Inch (Approx.).	Mesh.	Diameter Wire, Decimal of an Inch.
1·050	26·67	1		0·149
·742	18·85	$\frac{3}{4}$		0·135
·525	13·33	$\frac{1}{2}$		0·105
·371	9·423	$\frac{3}{8}$		0·092
·263	6·680	$\frac{1}{4}$	3	0·070
·185	4·699	$\frac{3}{16}$	4	0·065
·131	3·327	$\frac{1}{8}$	6	0·036
·093	2·362	$\frac{3}{32}$	8	0·032
·065	1·651	$\frac{1}{16}$	10	0·035
·046	1·168	$\frac{3}{64}$	14	0·025
·0328	0·833	$\frac{1}{32}$	20	0·0172
·0232	0·589	—	28	0·0125
·0164	0·417	$\frac{1}{64}$	35	0·0122
·0116	0·295	—	48	0·0092
·0082	0·208	—	65	0·0072
·0058	0·147	—	100	0·0042
·0041	0·104	—	150	0·0026
·0029	0·074	—	200	0·0021

CHAPTER X

COST OF INSTALLATIONS AND COST OF PRODUCING PULVERISED COAL

Capital Cost of Pulverised Coal Plants—Cost of Buildings—Capacity of Plant governs Economical Production—Net Savings at various Prices of Coal—Power Expenditure in Terms of Coal—Labour Required to Operate Plants—Itemised Power for Complete Plants—Maintenance Costs—Cost of Operating Pulverised Coal and Stoker-Fired Boilers—Comparison of B.Th.U. Values obtainable for Known Methods of Firing.

When an estimate of the economies and savings which can be effected by the use of fuel in pulverised form has been made, their values must be compared with the capital outlay required for a complete plant and equipment.

In presenting figures for capital expenditure upon pulverising plants of various capacities, and estimates for overall operating costs, and costs for conveying and burning, consideration can be given in these pages only to straightforward, or compact, plants. The cost of equipment for long-distance delivery, or for branch fuel-conveying systems, coal bins and burner gear at furnaces, boilers, etc., is much too complicated a matter to reduce to itemised costs for the numerous combinations of apparatus found in practice.

The additional cost of conveyors and fuel-burning equipment, fuel bins, fans, etc., may be taken at 20 % to 50 % of the cost of mill-house plant for normal works equipment and furnaces, but may reach 100 % when furnaces are small, numerous and scattered over a large area.

It is of little use to consider figures for cost of mill-house plants or operating expenses when estimates have been cut down to the lowest limits. Minimum costs are seldom experienced in practice. Ample allowance has, therefore, been made, in each instance, to cover all reasonable charges at present-day high prices for material, machinery, buildings, etc., and ample provision has also been made for maintenance, interest, depreciation, and labour.

In addition to the bare complement of plant necessary for drying and crushing the daily tonnage of coal, a series of columns has been added relative to further standby-plants. The provision of the latter slightly increases the overall running costs, due to interest and depreciation charges on idle machinery.

As to plant operation costs, much depends upon the size of the plant and upon the hours per diem during which it is operated. The type of the mills in use, the facilities for handling the raw coal, the nature of the coal (whether in slack or lump form and whether soft bituminous or hard anthracite), and also the particular method adopted for supplying the powdered coal to the furnaces and burning it therein, are factors which have considerable bearing upon operating costs.

Capital Cost of Pulverised Coal Plants.

Estimated capital expenditure for plants of various capacities, and the relative costs for operating them, are given in the following table, allowance being made for screw conveyors to deliver the fuel 300 ft. from the point of production. The cost of fuel storage-bins, burners, air-supply fans, and other accessories required at the furnaces is not included in this table.

COST OF PULVERISING PLANTS AND COST OF PULVERISED COAL PER TON (2240 LB.). (1920 Prices.)

Daily Output in Tons.	Labour. Cost per Ton.	Power. Cost per Ton.	Dryer Fuel. Cost per Ton. 2% of Coal Dried.	Repairs. Cost per Ton.	Without Stand-by Plant.				With Stand-by Plant.				Daily Output in Tons.
					Cost of Mill-House Plant, including Building.	Interest per Ton @ 6%.	Deprecia-tion per Ton @ 10%.	Total Pre-paration. Cost per Ton.	Cost of Mill-House Plant, including Building.	Interest per Ton @ 6%.	Deprecia-tion per Ton @ 10%.	Total Pre-paration. Cost per Ton.	
	s. d.	s. d.	d.	d.	£	s. d.	s. d.	s. d.	£	s. d.	s. d.	s. d.	
5	5 10	3 0	10½	4	3,500	2 9½	4 8	17 6	—	—	—	—	5
10	2 11½	2 10	10¼	4	6,700	2 8	4 5½	14 1¼	—	—	—	—	10
15	3 11	2 10	10¼	4	6,700	1 9½	3 0	12 8¾	—	—	—	—	15
20	2 11	2 10	10	4	9,300	1 9	2 10½	11 6½	10,300	1 11½	3 3	12 1½	20
30	1 11¾	2 10	10	4	9,300	1 3	2 1	9 3¾	10,300	1 4½	2 3½	9 7¾	30
40	2 2	2 8	10	4	9,300	0 11	1 7	8 6	10,300	1 0½	1 9	8 9½	40
50	1 2	2 8	10	4	11,100	0 10½	1 6	7 4½	12,700	1 0	1 8½	7 8½	50
60	1 0	2 8	10	4	11,100	0 9	1 3	6 10	12,700	0 10¼	1 5	7 1¼	60
70	0 10	2 8	10	4	11,100	0 7½	1 1	6 4½	12,700	0 8¾	1 2½	6 7¼	70
80	1 1	2 6	10	3¾	11,100	0 6½	0 11	6 2¼	12,700	0 7½	1 1	6 5¼	80
90	1 0	2 6	10	3¾	11,100	0 6	0 10	5 11¾	12,700	0 6½	0 11	6 1¼	90
100	0 10½	2 6	9¾	3¾	14,300	0 7	0 11½	6 0½	15,350	0 7½	1 0½	6 2	100
150	0 7	2 6	9¾	3¾	15,000	0 4¾	0 8	5 3¼	18,100	0 5¾	0 9¾	5 6	150
200	0 5¼	2 6	9¾	3¾	20,000	0 4¾	0 8	5 1½	25,500	0 6	1 0	5 6¾	200
250	0 6¼	2 6	9¾	3¾	20,000	0 4	0 6½	5 0¼	25,500	0 5	0 8¼	5 3	250
300	0 5¼	2 6	9¾	3¾	26,100	0 4¼	0 7	5 0	31,600	0 5	0 8½	5 2¼	300
350	0 4½	2 6	9¾	3¾	28,300	0 4	0 6½	4 10½	32,000	0 4½	0 7¼	4 11¾	350
400	0 5¼	2 6	9½	3¾	28,300	0 3½	0 5¾	4 9¾	32,000	0 4	0 6½	4 11	400
450	0 4¾	2 6	9½	3¾	31,000	0 3¼	0 5½	4 8¾	35,500	0 3¾	0 6¼	4 10	450
500	0 5¼	2 6	9¼	3¾	31,000	0 3	0 5	4 8¼	35,500	0 3½	0 5¾	4 9½	500
550	0 4¾	2 4	9¼	3¾	32,000	0 2¾	0 4¾	4 5¼	37,000	0 3¼	0 5½	4 6½	550
600	0 5¼	2 4	9¼	3¾	32,000	0 2½	0 4¼	4 5	37,000	0 3	0 5	4 6¼	600
650	0 5	2 4	9¼	3¾	32,000	0 2¼	0 4	4 4¼	37,000	0 2¾	0 4½	4 5¼	650
700	0 4½	2 4	9¼	3½	35,000	0 2½	0 4	4 3¾	41,000	0 2¾	0 4¾	4 4¾	700
750	0 5	2 4	9	3½	37,000	0 2½	0 4	4 4	42,500	0 2¾	0 4½	4 4¾	750
800	0 5½	2 2	9	3½	43,000	0 2½	0 4¼	4 2¾	50,500	0 3	0 5	4 4	800
850	0 5	2 2	9	3½	45,500	0 2½	0 4¼	4 2¼	53,500	0 3	0 5	4 3½	850
900	0 3½	2 2	9	3½	48,000	0 2½	0 4¼	4 0¾	54,000	0 2¾	0 4¾	4 1½	900
950	0 3¼	2 2	9	3½	49,500	0 2½	0 4¼	4 0½	55,200	0 2¾	0 4¾	4 1¼	950
1000	0 3¼	2 2	9	3½	53,500	0 2½	0 4¼	4 0½	59,500	0 2¾	0 4¾	4 1¼	1000

Figures given in this Table of Costs have been based on the following assumptions :

Labour at £4 per man per 44-hour week.

Power at 1½*d.* per kw. hour and an average allowance of 20 kw. hours per ton

of coal pulverised and delivered to the exit of mill-house, including power for all operations.

Dryers to be fired with pulverised coal, which is taken as 40*s*. per ton at the dryer burners; an average allowance of 2 % of the coal dried is made for dryer fuel, assuming the moisture content of coal to be reduced from 15 % to 1 %.

Yearly output is based on 300 working days.

Cost of Buildings.

As a further indication of the cost of buildings and pulverised coal mill-house machinery, the following table has been based upon standard plant and 1922 cost of materials.

APPROXIMATE ESTIMATED COST OF BUILDINGS AND STANDARD MILL-HOUSE EQUIPMENT AT 1922 PRICES FOR LABOUR AND MATERIALS.

Capacity of Mill-House Plant, tons (2240 lb.) per 24 hours.	Size of Building. Width × length in ft.	Cost of Building and Foundations.	Machinery with Air Separator Mills, and Foundations.	Machinery with Screen Separator Mills, and Foundations.
		£	£	£
20	20×40	1,300	6,750	6,300
30	20×50	1,300	7,200	6,600
40	20×50	1,300	7,200	6,600
80	25×65	1,620	9,000	8,100
150	25×100	2,420	13,000	11,250
250	35×100	4,050	17,000	15,300
350	35×120	4,050	20,500	19,500
400	35×140	4,050	26,000	23,500
500	40×125	4,850	30,500	27,000
650	40×125	4,850	35,000	29,000
800	40×150	5,650	37,000	34,250
950	40×150	5,650	42,500	38,000
1,100	40×150	5,650	46,000	41,500

Capacity of Plant Governs Economical Production.

It will be seen from the curves shown in Fig. 87, which are drawn from the figures given in the table, that the capital outlay and running costs for complete mill-house plants may prove quite out of proportion to the benefits to be realised when the daily tonnage of pulverised fuel is small. As a general rule, unless the cost of coal is abnormally high, it will not pay to instal complete plants of a capacity below 20 tons per 12 hours. The operation of small production plants of this size is usually confined to the daylight period; in other words, to one working shift of 10 hours or so.

Below 20 tons per day the self-contained pulveriser unit installed at each boiler, kiln or furnace may prove to be the more profitable investment. It does not necessarily follow that this course is always to be recommended, for under certain conditions the small self-contained units would be quite unsuitable. The difference between the cost of the small unit and that of complete mill-house equipment often appears attractive, but the latter affords flexibility of supply, whereas a separate self-contained unit must be installed for each furnace or kiln.

CAPITAL OUTLAY AND OPERATING COSTS OF SMALL SELF-CONTAINED UNITS.

Daily Output in Tons.	Output per Hour.	Labour Cost per Ton.	Power Cost.	Dryer Fuel.	Repairs per Ton.	Interest 6%.	Depreciation.	Total Cost.	Labour Hours per Day.	No. and Duration of Shifts.	Cost of each unit with Motor.
	Tons.	*s.* *d.*	*s.* *d.*		*d.*	*d.*	*s.* *d.*	*s.* *d.*		Hours.	£
5	½	2 7	2 10½	No	1½	9½	1 4	7 8½	10	2–5	1000
10	¾	1 9½	2 0	Dryer	1½	6¼	10	5 3	14	2–7	1250
15	1	1 4½	2 0	used.	1½	4¾	8	4 6¾	16	2–8	1500
20	2	8	1 7		1½	4¾	8	3 5¼	10	2–5	2000

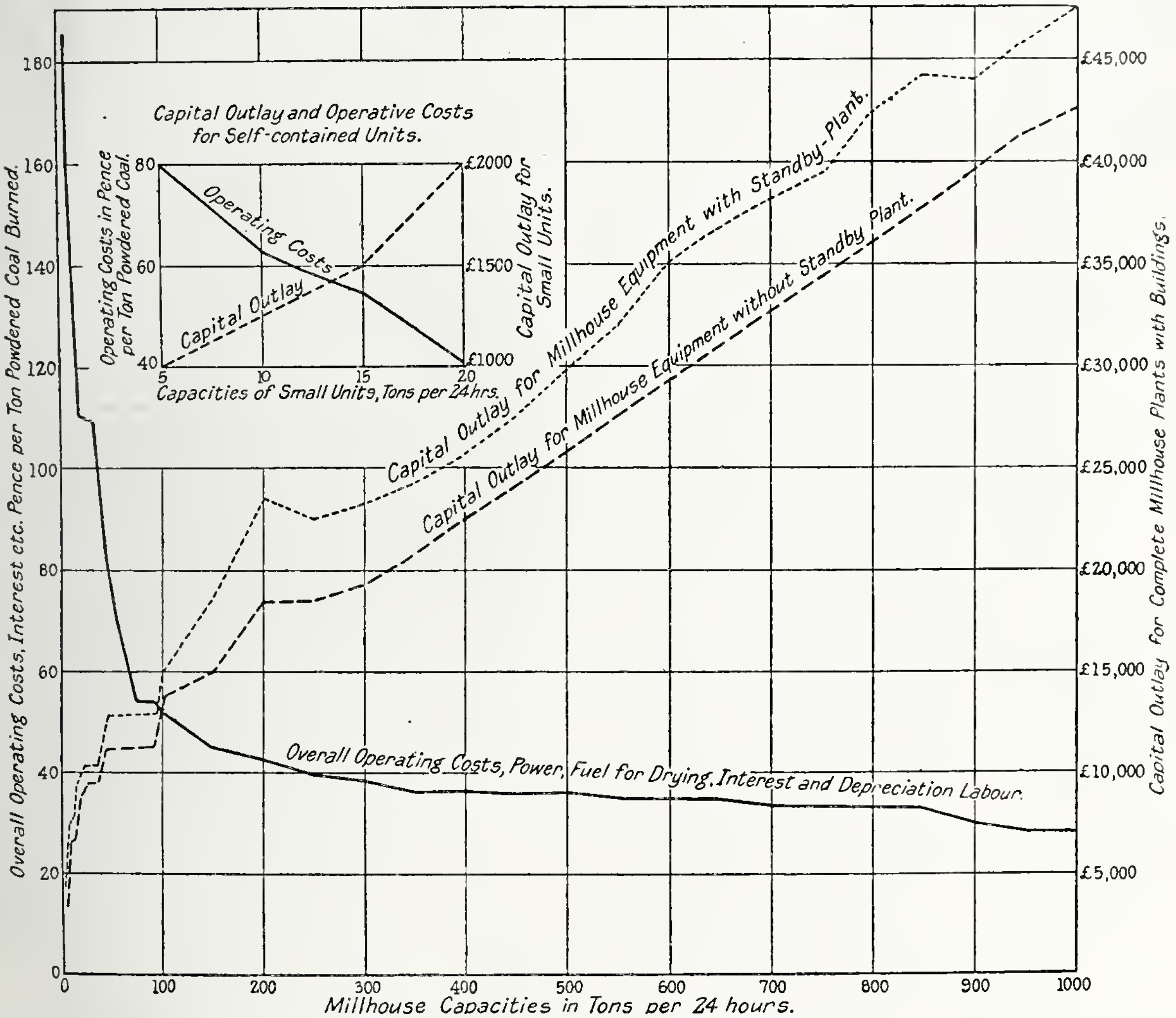


FIG. 87.—Graph showing Relation between Overall Production Costs and Capital Outlay for Complete Plants and Self-contained Pulveriser Units.

Net Savings at Various Prices of Coal.

If we take the cost price of raw coal and estimate the economy which can be introduced by adopting the pulverised fuel system, the relative savings can be seen by reference to Fig. 87. In this table it has been assumed that, as compared with present methods of firing, a 25 % reduction in fuel consumption can be made,

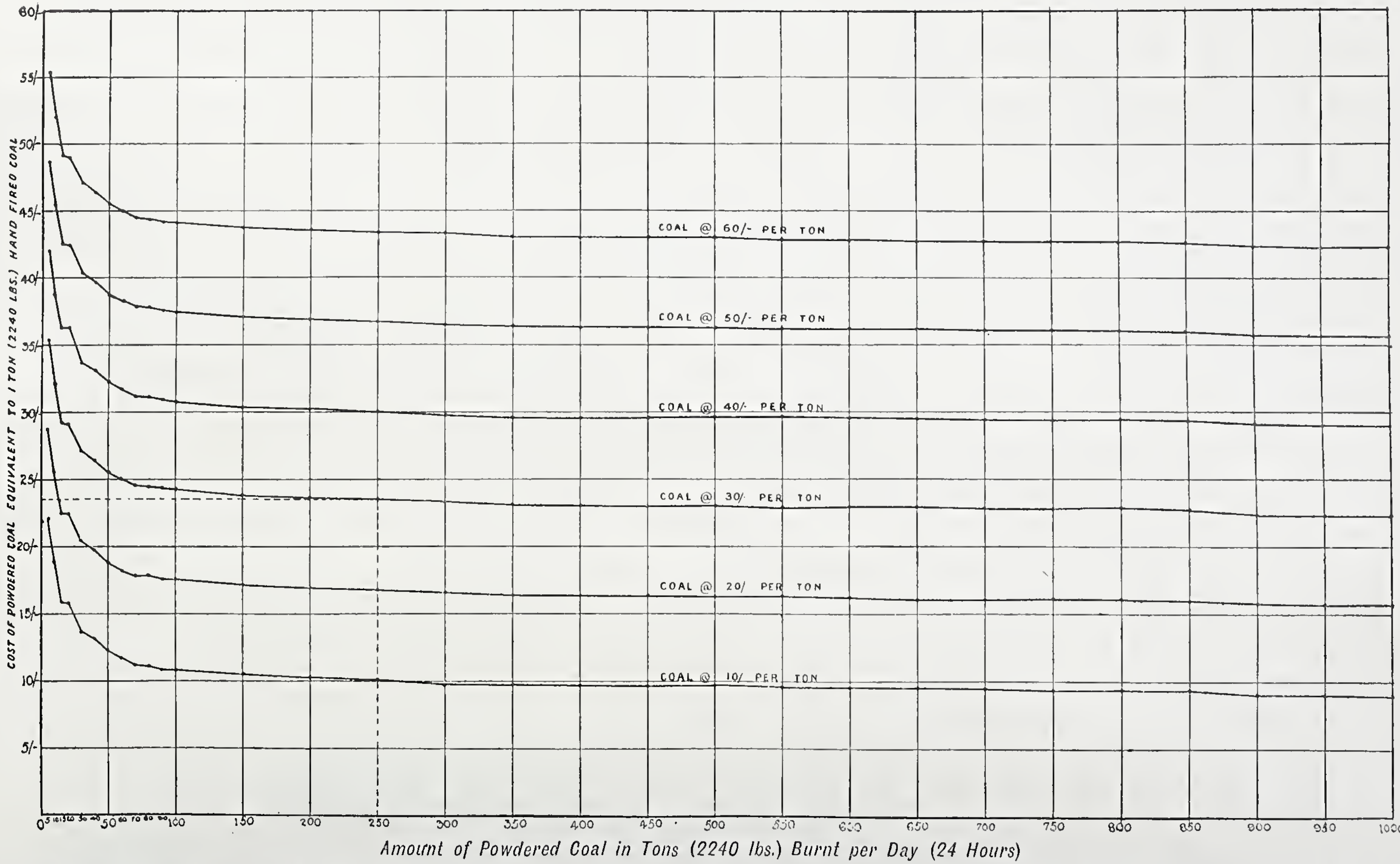


FIG. 88.—Cost of Powdered Coal for performing the same work as 1 ton (2240 lb.) of hand-fired coal. A saving of $33\frac{1}{3}\%$ in fuel by the use of powdered coal has been assumed, and, as an offset against the value of the fuel saving, the cost of preparing and burning powdered coal has been added. Costs given for plants of various capacities and for six prices of raw coal.

after allowing for the cost of preparing, transporting and burning pulverised coal, and the various curves have been plotted accordingly. The areas between the horizontal line for the price of coal per ton, 20*s*. to 60*s*., and the corresponding curves represent the net saving that will be realised for these coal values at any particular daily capacity of coal pulverising plant.

In addition, the very many important advantages and economies such as reduction in labour, increased output of furnaces, reduced metal loss, better work and better working conditions, etc., must not be lost sight of, for these in the aggregate may be more important and represent a greater saving than the actual reduction effected in fuel consumption, or the use of lower priced, lower grade coal.

Thus, for 200 tons per 24 hours the "savings," as shown by the curves, will be approximately :—

For coal costing 60*s*. per ton—a saving of 10*s*. for each ton of pulverised fuel burned.

For coal costing 50*s*. per ton—a saving of 7*s*. 6*d*. for each ton of pulverised fuel burned.

For coal costing 40*s*. per ton—a saving of 4*s*. 9*d*. for each ton of pulverised fuel burned.

For coal costing 30*s*. per ton—a saving of 2*s*. 3*d*. for each ton of pulverised fuel burned.

For coal costing 20*s*. per ton—a saving of 0*s*. 0*d*. for each ton of pulverised fuel burned.

The usual reduction due to the use of pulverised coal lies between 25 % and 60 % of the quantity of fuel as hand-fired.

Power Expenditure in Terms of Coal.

From the gross saving in fuel consumption at a furnace or boiler, the coal used in the production, conveying, and burning of the fuel must be deducted. The actual coal equivalent of the power required for general purposes can be taken as approximately 6 % of the weight of fuel consumed in powdered form. This figure has been determined as follows : it is assumed that for each unit of electricity used, 3 lb. of coal are required. The average overall power in a milling house is about 20 kw. hours per ton (2240 lb.) of coal pulverised.

20 kw. hours at 3 lb. coal	60·0 lb.
Fuel used in dryer at 2 % (for evaporating 10 % moisture in coal)	44·8 ,,
Power for conveying coal-dust at 2½ kw. hours per ton (screw conveyors say 600 ft.)	7·5 ,,
Power for air supply for burning powdered coal 7½ kw. hours per ton of coal	22·5 ,,
Raw coal used per ton of pulverised coal	134·8 lb. or 6%

It can be assumed for preliminary calculations that the equivalent of power in terms of fuel, together with the quantity of fuel used for drying, in the production, conveying, and burning of pulverised fuel will be under 10 % of the amount of coal applied at the furnace. Thus, if a saving in fuel consumption of 30 % is made over previous methods of firing a furnace, excluding labour and other savings incidental to pulverised coal firing, but inclusive of the cost of conveying coal for hand firing or other previous practice, the net equivalent saving in actual fuel burned will be 30 % less 7 %, or the net saving in cost of fuel purchased, whether as coal or in the form of power, will be 23 %.

Labour Required to Operate Plants.

In the following table are stated the number of pulveriser mills, and the attendant labour required for the tonnage capacities mentioned in the Table at p. 189 giving cost of pulverising plants.

Number of Fuller Pulveriser Mills and Corresponding Labour required for Pulverised Coal Plants.

Daily Output in Tons.	Output per Hour in Tons.	Number and Size of Mills.		Number and Size of Dryers.		Number of Men per Shift.	Labour Hours per Day.	Number of 8-hour Shifts per Working Day.	Maximum Output per Shift.	Approximate Output per Labour Hour.	Daily Output in Tons.
		Running Plant.	Stand-by Plant.	Running Plant.	Stand-by Plant.						
		Inches.	Inches.	Tons.	Tons.				Tons.	Tons.	
5	½	1–24	None	1– 4	None	1	16	2	4	0·31	5
10	2	1–33	,,	1– 4	,,	2	16	1	16	0·62	10
15	2	1–33	,,	1– 4	,,	2	32	2	16	0·47	15
20	2	1–33	1–33	1– 4	,,	2	32	2	16	0·625	20
30	2	1–33	1–33	1– 4	,,	2	32	2	16	0·94	30
40	2	1–33	1–33	1– 4	,,	2	32	2	16	1·25	40
50	4	1–42	1–42	1– 4	,,	2	32	2	32	1·55	50
60	4	1–42	1–42	1– 4	,,	2	32	2	32	1·87	60
70	4	1–42	1–42	1– 4	,,	2	32	2	32	2·19	70
80	4	1–42	1–42	1– 4	,,	2	48	3	32	1·63	80
90	4	1–42	1–42	1– 4	,,	2	48	3	32	1·87	90
100	6	3–33	1–33	1– 8	,,	2	48	3	48	2·1	100
150	8	2–42	1–42	1– 8	1– 8	2	48	3	64	3·1	150
200	12	3–42	1–42	1–10	1–10	3	48	2	96	4·2	200
250	12	3–42	1–42	1–14	1–14	3	72	3	96	3·5	250
300	16	4–42	1–42	1–14	1–14	3	72	3	128	4·2	300
350	16	4–42	1–42	1–14	1–14	3	72	3	128	4·9	350
400	20	5–42	1–42	2–10	1–10	4	96	3	160	4·2	400
450	20	5–42	1–42	2–10	1–10	4	96	3	160	4·7	450
500	24	6–42	1–42	2–14	1–14	5	120	3	192	4·2	500
550	24	6–42	1–42	2–14	1–14	5	120	3	192	4·6	550
600	28	7–42	2–42	2–14	1–14	6	144	3	224	4·2	600
650	28	7–42	2–42	2–14	1–14	6	144	3	224	4·5	650
700	32	8–42	2–42	2–14	1–14	6	144	3	256	4·9	700
750	36	9–42	2–42	4–10	1–10	7	168	3	288	4·5	750
800	40	10–42	3–42	4–10	1–10	8	192	3	320	4·2	800
850	40	10–42	3–42	6–10	1–10	8	192	3	320	4·4	850
900	40	5–57	1–57	4–14	1–14	6	144	3	320	6·25	900
950	48	6–57	1–57	4–14	1–14	6	144	3	384	6·6	950
1000	48	6–57	1–57	4–14	1–14	6	144	3	384	6·9	1000

Itemised Power for Complete Plants.

As to the power absorbed in operating the machinery in a coal-pulverising house, a detailed power sheet for a Fuller installation is given below.

Equipment.	Power consumed in Crushing, Drying, and Pulverising 160 Net Tons of Bituminous Coal per Day (24 hours). (Short Tons = 2000 lb.)			
	Capacity per Hour.	H.P. Required.	Hours Operating Daily.	Total H.P. Hours Daily.
One 18″ × 18″ single roll crusher	30 tons	15	5·5	82·50
Elevator for crusher	30 ,,	7·5	5·5	41·25
One 4′–6″ × 42″ Fuller-Lehigh Dryer	10 ,,	5	16	80·00
Dryer Fan	—	4	16	64·00
,, Feeder	—	1	16	16·00
,, P.C. Fan	—	1	16	16·00
,, ,, Feeder	—	$\frac{1}{2}$	16	8·00
,, ,, Elevator	10 tons	5	16	80·00
,, ,, Screw Conveyor	10 ,,	2	16	32·00
Two 42″ Fuller Pulverising Mills	75 ,,	110	23	2530·00
Elevator for Mills		7·5	23	172·50
				3122·25 h.p. hrs.

$$\frac{3122{\cdot}25 \text{ h.p. hrs.}}{1{\cdot}34} = 2330 \text{ kw. hrs. and } \frac{2330 \text{ h.p. hrs.}}{160} = 14{\cdot}56 \text{ kw. hrs. per ton.}$$

Thus, it will be seen that the power taken for operating the machinery enumerated above is but 14½ kw. hrs. per ton of 2000 lb., or, say, 15¾ kw. hrs. per ton of 2240 lb.

An allowance of 20 kw. hrs. per ton of 2240 lb. of coal is the conservative figure taken by the author for his various calculations for power used in pulverised coal plants, and 30 kw. hrs. as a general indication of the overall power used collectively at the mill-house, and for conveying and burning the fuel at furnaces placed throughout an iron or steel works of normal layout. The assumption is naturally made that transportation distances are not abnormal.

If the total power as given above is sectionalised for the different operations, it will be seen that the total power is divided as to :—

3·96 % or 123·75 h.p. for crushing and elevating the coal to crushed coal-storage bin.

9·55 % or 296·00 h.p. for drying and elevating the dried coal to bins above pulverising mills.

86·49 % or 2702·50 h.p. for operating the Fuller mills and elevating the pulverised coal to storage bin.

100 % or 3122·25 h.p. total for 160 (net) tons per day.

In further confirmation of the figure assumed for power absorbed in the production of pulverised coal, actual meter readings of power circuits to motors running a small Fuller mill equipment ($2\frac{1}{2}$ tons per hour) and screw conveyors, can be quoted, thus :—

Machine Item.	Brake h.p. absorbed.	Kw. hrs. per ton.
Coal Crusher	6·3	0·35
Crushed Coal Elevator	4·8	0·25
Rotary Coal Dryer	4·8	1·20
Dry Coal Elevator	1·93	0·50
$2\frac{1}{2}$ tons per hour Fuller Screen Separator Pulveriser Mill	36·70	15·0
Pulverised Coal Elevator	1·94	0·50
375 ft. of screw conveyor in two lengths	5·15	1·25
Total power per ton of pulverised coal—Production and conveying 375 ft.		19·05

For large capacity mills the total power, excluding that required for conveying the fuel, can be as low as 12 kw. hrs. per ton; as against the 14·5 kw. hrs. per ton (2000 lb.) quoted above for 160 tons per 24 hours. The allowances, as mentioned above, of 20 kw. hrs. per ton for mill-house machinery, and 10 kw. hrs. for conveying and burning the fuel under normal conditions, are therefore reasonably conservative.

Maintenance Costs.

As an indication of the division of labour, power, and repair costs for a pulverised coal mill-house plant producing, say, 40,000 tons per annum, the following data have been compiled at the works of an American Portland Cement Co., where a Fuller mill installation has been in operation for some years.

Total cost of Operating.	Labour	\$5574·04	Cost per ton (2240 lb.)	\$0·1519
,, ,, ,,	Material	\$130·41	,,	\$0·0035
Total cost of Repairs.				
Dryers, Elevators, etc.	Labour	\$655·71	,,	\$0·0178
,, ,, ,,	Material	\$511·72	,,	\$0·0139
Fuller Mills.	Labour	\$103·94	,,	\$0·0028
,,	Material	\$799·49	,,	\$0·0212
Motor Repairs.	Labour and Material	\$23·07	,,	\$0·0006
Mill and Motor Belting.		\$15·72	,,	\$0·0004
Total cost of Power.		\$3768·90	,,	\$0·1027
Total cost of Labour, Material and Power		\$11583·00		\$0·3148

Total number of tons of coal p.a. 36,682 = say, 122 tons per day.

In the following estimate the sectional operating costs for a Quigley standard plant of 100 tons per day capacity are stated as percentages of the total overall cost for production, conveying, and burning, and provision is made for maintenance and depreciation at 14 % of the cost of the plant.

The relative costs for each operation are found to be approximately :

For crushing, drying and delivery to dry coal bunkers	27 %
For pulverising, and delivery by air separator fans to pulverised fuel bunkers	23 %
For distribution by blowing tank system to furnace bins and for electric power for air supply fans	22 %
Fixed charges, maintenance and depreciation at 14 %	28 %
Total operating costs, including all labour costs	100%

A rough idea of operating and maintenance costs for a coal-dust and air distribution plant is given below for a small installation having a capacity of 4 tons per hour, the figures quoted being taken from actual records.

The running costs for a pulverised coal plant operating on the air and coal-dust mixture system for conveying the fuel to the furnaces are somewhat heavier than for other systems described. It is generally found that repair and power costs are somewhat increased owing to the high velocity air distribution required and the wear and tear upon wheels and casings of mixing fans.

	Yearly Record. Cost per ton. $
Operating Labour	0·285
Supplies and Repairs	0·705
Power	0·499
Laboratory Charge	0·014
	$1·503

Cost of Operating Pulverised Coal and Stoker-Fired Boilers.

Practical operating results at a power plant using both powdered coal and fuel oil have proved that the increased efficiency from powdered coal—probably due to the radiant effect of the ash in suspension in a boiler furnace—is sufficient to offset the actual increased cost of pulverising, handling, and firing of solid fuel as compared with the cost of firing fuel oil. Thus the comparative cost can be considered on a B.Th.U. basis, irrespective of the amount and character of the ash, which in the ordinary practice of firing makes it difficult to maintain combustion, and which decreases so largely the overall efficiency of the combined furnace and boiler.

Taking a specific instance, with run-of-mine bituminous coal of about 12,500 B.Th.U. content per lb., costing $3·75 per ton, and fuel oil of about 19,000 B.Th.U. content per lb., costing 90 cents per barrel, both delivered alongside the power plant, the heat value purchased per dollar would be 6666 B.Th.U. for coal, and 6561 B.Th.U. for fuel oil, and the net operating result, in terms of cost for steam produced, shows a slight difference in favour of the powdered coal.

In the following table the total operating expense for powdered coal firing for a 22,400 h.p. Nominal Rating Boiler Plant is compared with that for stoker firing.

The coal as fired was bituminous, containing moisture, 0·8 %; volatile matter, 33·58 %; fixed carbon, 56·02 %; ash, 9·6%; sulphur, less than 1%; B.Th.U. per lb., 13,380. There were 14 B. and W. boilers, each rated at 1600 h.p., and operating 24 hours per day at 2000 h.p.

	Item.	Powdered Coal Firing.	Stoker Firing.
1	Total cost of coal per net ton, as fired (item 5 and 38)	\$3·7141	\$3·6517
2	Boiler h.p. hours developed per net ton of coal (2000 ÷ item 16)	639	583
3	Boiler h.p. hours developed per dollar expended for fuel and labour	172	160
4	Cost of firing per 100 boiler h.p. hours developed	58 c.	61·5 c.
5	Cost of coal, per net ton, alongside	\$2·80	\$2·80
6	Hourly rate and hours per day for firemen (24 hours at 45 c.)	(3)[1] \$32·40	(5)[1] \$54·00
7	Hourly rate and hours per day for assistant firemen (24 hours at 43·5 c.)	(3) \$31·22	(5) \$52·20
8	Hourly rate and hours per day for ash handlers (10 hours at 42 c.)	(2) \$8·40	(6) \$60·48
9	Hourly rate and hours per day for millers (20 hours at 54 c.)	(1) \$10·80	—
10	Hourly rate and hours per day for millers' helpers (20 hours at 43·5 c.)	(3) \$26·10	—
11	Hourly rate and hours per day for conveyor attendant (20 hours at 45 c.)	(1) \$9·00	(1) \$10·80
12	Hourly rate and hours per day for inspector (24 hours at 54 c.)	(1) \$12·96	(2) \$25·92
13	Total labour per 24-hour day	(14) \$130·88	(19) \$203·40
14	B.Th.U. utilised in boiler and superheater	10,704	9,767·4
15	Pounds water evaporated from and at 212° per lb. of coal	11·03	10·065
16	Pounds coal per boiler h.p. hour	3·13	3·43
17	Pounds coal per hour during banked period	—	11,200
18	Pounds coal per day while operating	2,524,032	2,765,952
19	Pounds coal per day while banked 0·5 lb. per h.p. capacity per hour	—	67,200
20	Pounds coal per day, total for plant	2,524,032	2,833,152
21	Tons coal per year, total	460,635·8	517,051·2
22	Tons coal per hour in preparation plant (20 hours per day)	66	—
23	Cost of preparation plant building, including foundation and bins	\$80,000	—
24	Cost of preparation plant machinery and equipment	220,000	\$25,000
25	Cost of distributing-system machinery	75,000	See item 33
26	Cost of distributing-system supports	See item 33	—
27	Cost of boiler bins and supports	,, ,, 33	—
28	Cost of boiler-firing machinery and equipment	240,000	487,000
29	Cost of boiler furnaces	\$4,000	See item 28
30	Cost of boiler-room changes when necessary	—	—
31	Cost of ash-handling equipment	20,000	65,000
32	Cost of soot-blower system	10,000	10,000
33	Cost of boiler, installed	\$1,456,000	\$1,456,000
34	Total cost of boilers, coal plant and equipment	\$2,185,000	\$2,043,000
35	Total cost of preparation per ton of coal prepared	0·3325	0·009
36	Total cost of handling in distributing system, per ton	0·0440	0·0494
37	Total cost of boiler firing, per ton fired	0·5376	0·7933
38	Total cost of preparing, distributing, and firing coal per net ton (items 35, 36, and 37)	0·9141	0·8517

[1] Number of men required.

From yet another source, figures can be quoted which may be regarded as official, for the cost of burning coal under boilers by means of stoker and pulverised coal equipment. The Committee on Power Generation of the American Electric Railway Association, from exhaustive inquiries and data obtained, compiled and subsequently published a table giving comparative costs and figures for plant, operation, maintenance, etc. Costs are given therein for burning various grades of fuel from anthracite culm to bituminous coal, using the pulverised fuel system and Underfeed Stoker plant, the handling, storage, etc., conditions being equal for the stoker plant and pulverised fuel plant. From this table two classes of fuel only have been selected for illustration, viz. lignite and bituminous coal, and one rating only of boiler, viz., 200 % of maker's rating, the basis of estimate being made upon an assumed boiler capacity of 12 B. and W. boilers, each of 600 h.p. normal rating.

	Pulverised Coal Firing.		Underfeed Stoker Firing.	
	Lignite.	Bituminous Coal.	Lignite.	Bituminous Coal.
Furnace volume cu. ft. per boiler	3,600	3,000	1,500	1,050
Maximum combined efficiency	73%	79%	70%	77%
Per cent. rating at which maximum efficiency occurs	140%	140%	130%	100%
Combined efficiency at maximum load	72%	76%	67%	70%
[1] Power required to drive stokers	—	—	0·29	0·23
[1] Power required for handling green coal and clearing ashes per annum	0·06	0·04	0·24	0·15
[1] Power required to drive complete pulverising and conveying plant to furnaces per annum	4·08	2·58	—	—
Coal required per annum for drying (tons)	6,300	1,700	—	—
Total fuel consumed per annum as received (tons)	185,600	117,200	196,600	117,800
Total power required for all purposes (million kw. hours per annum)	4·91	3·30	1·85	1·58
Cost of complete plant erected	$377,000	$308,000	$258,500	$230,500
Fixed charges at 15% per annum	$56,500	$46,200	$38,800	$34,600
Total cost of maintenance, stoker or pulveriser plant, forced and induced draught fans, etc.	$33,980	$22,475	$34,180	$34,660
Total cost of operation (labour)	$57,840	$50,340	$108,590	$69,590
Total cost per annum (exclusive fuel and power)	$148,320	$119,015	$181,570	$138,850

[1] Power given in million kw. hours per annum.

This table of costs is of exceptional value, both because it comes from such a reliable source, and because it shows the relation between the total cost of pulverised coal plant and that of stoker plant, and the advantages attaching to the former in respect of maintenance, and, especially, labour costs for operation.

Comparison of B.Th.U. Values Obtainable for Known Methods of Firing.

As a general indication of the relation between the relative values of the various known methods of heat production, the curves in Fig. 89 have been plotted to show

the number of B.Th.U. obtainable for one penny, when using pulverised fuel, producer gas, fuel oil, and town gas, respectively.

In order to arrive at a basis which is as fair as possible for comparison with other fuels, the operating cost for running a powdered-coal plant, and the overall expense connected with conveying and burning the fuel at the furnace, have been added to the cost of raw coal.

It is presupposed that the producer gas will be burned under natural draught conditions.

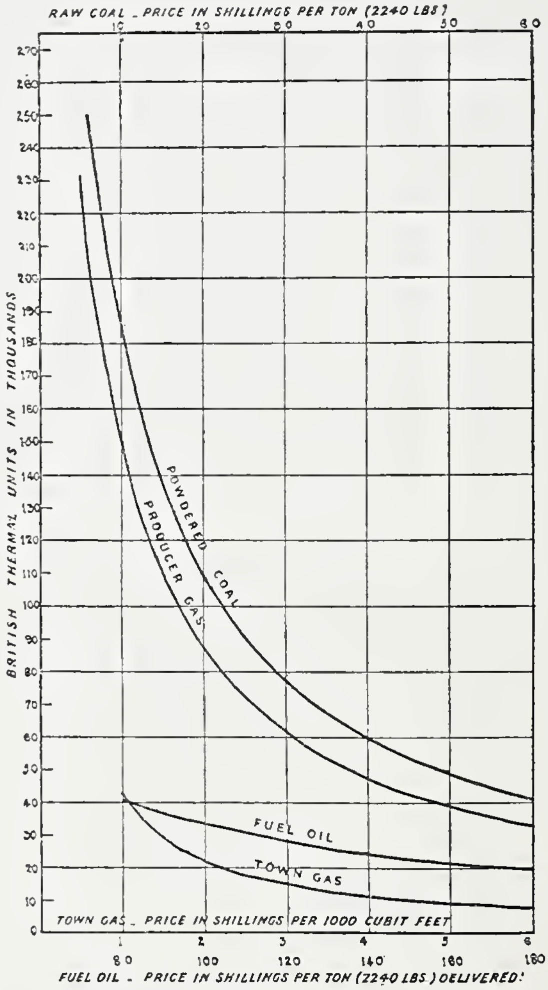


Fig. 89.—The number of B.Th.U.'s secured for one penny for commercial fuels at various prices.

For powdered coal, fuel oil and town gas, the cost of power at $\frac{3}{4}d.$ per unit has been allowed for air blowers.

The calorific value of the raw coal has been assumed at 14,000 B.Th.U. per lb., that of oil at 19,000 B.Th.U., and town gas 550 B.Th.U. net per cu. ft.

On this question of the cost of various descriptions of fuel, and the relative thermal values obtainable for one cent, the following figures are quoted from a paper read by J. E. Muhlfeld before the Engineers' Society of Western Pennsylvania.

The figures given have been taken from *The Iron and Coal Trades Review*,

August 27th, 1920, together with the comparison which Muhlfeld makes between cost of plant, upkeep, and general expenses for pulverised coal firing, and for mechanical stoker firing respectively.

The Appendix to this paper, given in an abridged form below, sets forth the relative values of powdered and stoker-fired coal, but it is also of interest to note the comparative purchasing power of one cent for various fuels, based on their heat values at the furnace.

Powdered Bituminous Coal.

B.Th.U. per lb.	12,000
B.Th.U. per ton (2000 lb.)	24,000,000
Cost per ton (including handling, pulverising, and transmission to furnace)	\$5·50
B.Th.U. for one cent.	43,636

Natural Gas.

B.Th.U. per cu. ft.	960
B.Th.U. per 1000 cu. ft.	960,000
Cost per 1000 cu. ft.	\$0·25
B.Th.U. for one cent	38,400

Producer Gas.

B.Th.U. per cu. ft.		130
Producer efficiency, %		78
Cost of coal per ton (2000 lb.)	\$4·95	
Cost of labour	0·65	\$6·00
Cost of power	0·40	
B.Th.U. available in gas from one ton of coal (12,000 B.Th.U. per lb. of coal)		18,720,000
B.Th.U. for one cent		31,200

Fuel Oil.

B.Th.U. per lb.	19,000
Pounds per gallon (Imperial gal. = 1·2 U.S.A. gal.)	7·3
B.Th.U. per gallon (U.S.A. gal. = 0·83 Imperial gal.)	138,700
Cost per gallon	\$0·09
B.Th.U. for one cent	15,411

CHAPTER XI

METHODS OF CONVEYING PULVERISED FUEL

The Choice of a Fuel-Conveying System—The Several Systems of Conveying Pulverised Fuel—Screw Conveyor System—Quigley and Grindle Blowing Tank Systems—The Holbeck or Bonnot Air-Mixture System—Bergman and Covert Air-Mixture Systems—The Fuller-Kinyon Pumping System—The Pulco Pump—Measuring the Quantity of Pulverised Fuel Delivered—Cyclone Separators—Summary of Advantages and Disadvantages of Screw Conveyor, Blowing Tank, Air-Mixture and Pumping Systems.

In conveying pulverised coal in bulk for burning in furnaces or under boilers, the chief desiderata are : (1) the elimination of conditions which may render explosion possible; (2) efficient drying of the raw coal; (3) avoidance of complicated equipment; (4) reliability of fuel supply.

In the following pages brief descriptions of standard methods of conveying pulverised coal, and the equipment used are given. The question of the explosibility of pulverised coal in air is fully dealt with in Chap. II, and is only briefly referred to here.

A number of accidents of a serious nature have occurred during the past years, many of which were due to conveying the pulverised fuel in suspension in a current of air.

In present-day systems embodying this method of conveying the fuel, the mixture of coal-dust and air as supplied through the conveying pipes is not of an explosive nature so long as correct conditions are maintained. There is then no danger of explosion or accident. But it often happens that precautions may become relaxed because of long periods of immunity from accident, or that a change in certain conditions creeps in unnoticed, and the mixture may then become highly explosive; under these conditions, should there occur a flash back from a working furnace, a serious explosion is almost bound to result. This method of conveying pulverised fuel is, however, the only feasible one for the supply of fuel to groups of small furnaces, and in the author's opinion it should be rigidly restricted to such uses.

A serious explosion can hardly occur within relatively small diameter pipes, whereas the explosion of a big volume of mixture in a large diameter trunk main is much more likely to happen when conditions are favourable, and naturally there will be serious consequences when it does happen.

For this reason, and in consequence of several such accidents in the past, it is now accepted practice to store the powdered coal in bins at the boilers or furnaces, thereby eliminating all possible danger of explosion during the period of conveying it thither.

It is preferable, though not always essential, that coal should be dried to the standard of 1 % moisture before feeding it to the pulveriser mills. The required degree of fineness, and full mill output, cannot be obtained if the coal contains an excess of moisture. Furthermore, moist pulverised fuel will tend to clog or to pack in the conveyor troughs or pipes, and when lying in the storage bins moist fuel is the more likely to become over-heated to the extent of commencing spontaneous combustion.

The main differences between the various recognised types of pulverised coal plants or systems are centred round the methods advocated for transporting the fuel to the furnaces.

In America, during the transition stages of development in the preparation and application of pulverised coal, and down to about the year 1918, as evidenced by plants installed, opinion as to the best method of transporting and burning pulverised fuel was perhaps fairly divided between the advisability of conveying the fuel, as soon as pulverised, to storage bins at the furnaces or boilers, and the alternative arrangement of mixing the pulverised fuel with air at the mill-house and distributing this mixture through trunk mains.

The first method necessitates the use of either screw conveyors or some other means of forcing or pumping the fuel to furnace bins. It also involves the subsequent use of screw feeders attached to the bottom outlets of the bins, and the rotation of the screw feeder spindles by power obtained from line shafting, or by small constant speed, or variable speed motors.

The alternative method, the fuel and air mixture system, introduces additional and somewhat complicated mechanism at the mixing end, namely, inside the mill-house, and necessitates the use of relatively large-diameter delivery mains to form a continuous circuit back to the source of supply. On the other hand, this system obviates the use, and therefore the cost of bins at the furnaces, together with the cost of screw feeders and motors for driving them.

Many people adopted the air and fuel mixture system as affording a ready means of conveying the fuel to furnaces scattered throughout a works. In a great many other instances, purchasers have stated their preference for the more reliable method of providing for a supply of pulverised fuel at the point where it is actually to be burned. It was the cost and unreliability of the older designs of small variable speed motors used for operating the screw feeder spindles that decided many users to adopt the air and fuel mixture system.

The introduction of the air-pressure system, whereby the fuel is forced or squirted through ordinary 3 in. or 4 in. pipes into the furnace bins, and the development of the constant-speed feeders which can be run by belting or chain from line shafting, won over to the bin system many engineers who previously had preferred the air-mixture method.

Subsequent experience has certainly led to a decision in favour of conveying the fuel to bins at the furnaces as affording greater security and flexibility when considerable quantities of coal are to be burned. For this purpose the screw conveyor has proved to be inexpensive in upkeep and thoroughly reliable, although at times inconvenient and somewhat costly to instal.

When in America in 1918, the author was shown screw conveyors at some of the older plants which had been in operation continuously for ten or twelve years, and were then still in good condition, notwithstanding exposure to all weathers since the day they were put up.

Screw conveyors have not by any means been discarded in America in favour of the newer systems of fuel supply. Some notes by Bergman upon the reliability of screw conveyors are given below :—

"Conveying the coal by means of screw conveyors is the most conservative way, and the safest and most satisfactory from an operating point of view. The screw conveyors last practically indefinitely, and the only repair work required is once a year to take out the bearings and have same re-babbitted and put in place. This system can also be made practically fool-proof from an operating point of view, and requires very little power.

"At the plant I operated, the furnace furthest away from powdered coal production plant was supplied through 1100 ft. of conveyors running in different directions. I tested this conveyor system to find out how much moisture was taken up by the coal, and found this amount to be so small that it could be disregarded. During an exceptionally heavy rain, the conveyor system was completely emptied out, standing empty for 6 hours, being exposed to the weather, the largest portion of the system being out of doors. When again starting up the system, the pulverised coal fed into it had a moisture content of 0·60 %. The coal delivered into the bin at the farthest end, having gone through 1100 ft. of this system, had a moisture content of 0·66 %."

To transmit heavy quantities of pulverised coal long distances by mixing the fuel with a high-velocity air-conveying medium is not an economical method, although under certain conditions it is a convenient one. It always means the provision of a loop system, so that surplus fuel not used en route can either be extracted and returned to the fuel bin, or added to fresh fuel and air before again circulating the mixture through the mains. This is a very wasteful proceeding so far as power is concerned. A high-speed mixing fan of considerable power must be used, also a long length of loop main. For 1000 ft. out there must be a 1000 ft. return, and, probably, two additional booster fans of, respectively, three-quarters and one-half the power of the initial propelling fan, may have to be inserted in the ring. Should there be an unequally distributed and varying load on the mains, it is quite possible for one of the intermediate booster fans to starve the fuel supply on the previous section. The continuity of fuel supply is dependent not only upon the initial high-speed mixing fan, but, in many cases, upon the secondary boosters, the failure of any one of which breaks down the whole fuel supply system.

It therefore appears to be much safer to transport the fuel as a semi-solid unmixed with air, and by means of positive mechanism such as a slow-running screw conveyor, or under pressure through pipe lines. By this means it becomes possible to provide adequate storage of fuel at the furnaces or boilers, so that during any

period of breakdown in the mill-house or of supply lines, the furnace plant will not be shut down. This is a point of vital importance when considering plants for use with melting furnaces or steam boilers. In the first case a discontinuance of the fuel supply might mean the setting of molten metal and the dismantling of furnaces in order to remove the metal, and in the latter the complete closing down of the power plant.

The Choice of a Fuel Conveying System.

The right choice of a method of transporting pulverised coal from the pulveriser mills to the furnaces or boilers can be made only after due regard has been given to all circumstances. The ultimate decision will rest upon many considerations such as : the position of furnaces; quantity of fuel to be transmitted over a given time; overall distance of transportation; fuel burning rate and accessibility of furnaces; the consequence of failure of fuel supply; duration of operation.

For a range of boilers or furnaces close at hand to the pulveriser mill-house, it would involve needless expense to instal the air-pressure system with duplicate sets of motor air compressors, blowing tanks, switch valves, etc., when a simple straight-line screw conveyor will serve the purpose, and an equipment of this type will probably show economy in respect of first cost, maintenance, and absorption of power.

For outlying furnaces or boilers scattered over a wide area, the air-pressure blowing system or screw-pump method would be cheaper to instal, and would be more satisfactory than screw conveyors.

For intermediate distances and for distribution lines running in several directions, the Fuller-Kinyon pumping system, which is now operating at several works in America, has proved reliable and efficient.

Reference is made later to the Bergman air-mixture system, with which the surplus fuel not used in the furnaces is returned to a cyclone separator, and the coal which is extracted therein, instead of being returned to the main fuel-bin, as in the Holbeck system, is returned to the coal feed screw. The liberated air, with any fine dust which may remain still in suspension, is taken direct to the mixing fan inlet instead of being exhausted into the atmosphere. Thus there is a certain saving both of power and fuel, no dust whatever escaping to the atmosphere.

Pulverised fuel that has traversed the loop, during which time it has been in contact with the air in the supply mains, will have become slightly oxidised, and, moreover, it is always the coarser particles that are returned to the cyclone separator. By taking this returned surplus fuel direct to the feed screw, as in the Bergman system, the partly oxidised and relatively coarse fuel is at once mixed with fresh coal. By returning the semi-oxidised coarse coal to the storage bunker there is at times a tendency for a thick layer of poor grade coal to become deposited on the supply of fuel. When this layer of coarse coal ultimately reaches the mixing fan it is remixed with air and delivered into the supply mains, with the result that spasmodic or difficult firing conditions will be realised until the layer of coarse coal in the bunker has been used up.

From the foregoing preliminary remarks it will no doubt be gathered that the

supply of pulverised fuel should be located at as many convenient points as is found possible or practicable. It is certainly not very wise to rely entirely upon fuel stored in bulk at one point, *i. e.* at the point of production, which may well be at a considerable distance from the location of furnaces in which the fuel is to be burned. Apart from any question of accidental breakdown of the transport, which would cut off the entire supply of fuel, there is always less likelihood of spontaneous combustion occurring in small bins than in one large mass of pulverised coal.

With the Simon-Carves plants, the methods adopted for conveying pulverised coal are the ordinary screw conveyor, or a compressed air forcing system, very similar to that originally used under the Quigley System. Fuel separators as installed for this system are shown in Fig. 103.

A Simon-Carves plant (Fig. 25) for a number of small furnaces utilises the usual air and coal-dust mixture system and is somewhat similar to the Bergman System, in that the return supply pipe is directly connected to the inlet of the mixing fan. The surplus fuel is not separated out in a cyclone separator, as in the Holbeck, or Bonnot, System.

The Several Systems of Conveying Pulverised Fuel.

The several methods of fuel transportation can thus be divided into five main groups :—

1. By screw conveyors feeding into bins fitted at the furnaces or sub-station :—

   (*a*) thereafter fed through screw controllers to the burners;
   (*b*) the use of sub-stations equipped with rotary fans into which the fuel is fed, and the mixture of air and coal-dust distributed to the furnaces through a system of supply piping;
   (*c*) from the furnace bin the coal can be syphoned by the ejector action of compressed air.

2. By means of an "Air Pressure Transportation" system, by which the pulverised coal is delivered in known quantities into blowing tanks at the mill-house. Compressed air is applied to the blowing tanks for the purpose of forcing any given quantity of coal through small supply pipes to the bins at the furnaces; *a*, *b* and *c* subsidiary systems given above for No. 1 method can be quite as readily adopted as subsidiary methods of distribution.

3. By means of the "Air Mixture" system, in which the coal-dust is mixed at the mill-house with approximately half the quantity of air required for its combustion. The primary air supply is effected at a pressure of from 10 to 12 ounces per sq. in. and at a speed of 90 ft. per second. The mixed coal and air at this velocity is delivered through the main supply pipes to the branch service at the furnaces. The main supply pipe must of necessity take the form of a complete loop from and to the mill-house, at which point the coal-dust returned is generally extracted in a cyclone separator and re-delivered to the pulverised coal storage bin or to the mixing fan. For long lengths of main supply piping, one or more booster fans would be introduced into the circuit to maintain the requisite velocity of the mixture.

4. By means of the "Fuller-Kinyon Pumping" or "Pulco Pumping" system. With the former a screw pump is used, and so placed as to receive the pulverised coal at the discharge from the mill. In the latter a rotary disc pump is used. In each case a small quantity of compressed air is introduced into the fuel "as a lubricant" to prevent packing in the delivery pipes. In this way fuel can be delivered to any number of bins, supply being controlled by switch valves.

5. When only small quantities of pulverised coal are required at distances far remote from a pulverising plant, the delivery of coal dust can be made by tank wagon, in enclosed steel barrels, or in special sacks. These methods are now in daily use in several localities where there is a demand for coal-dust for central heating systems in offices, and public buildings, and for general works requirements

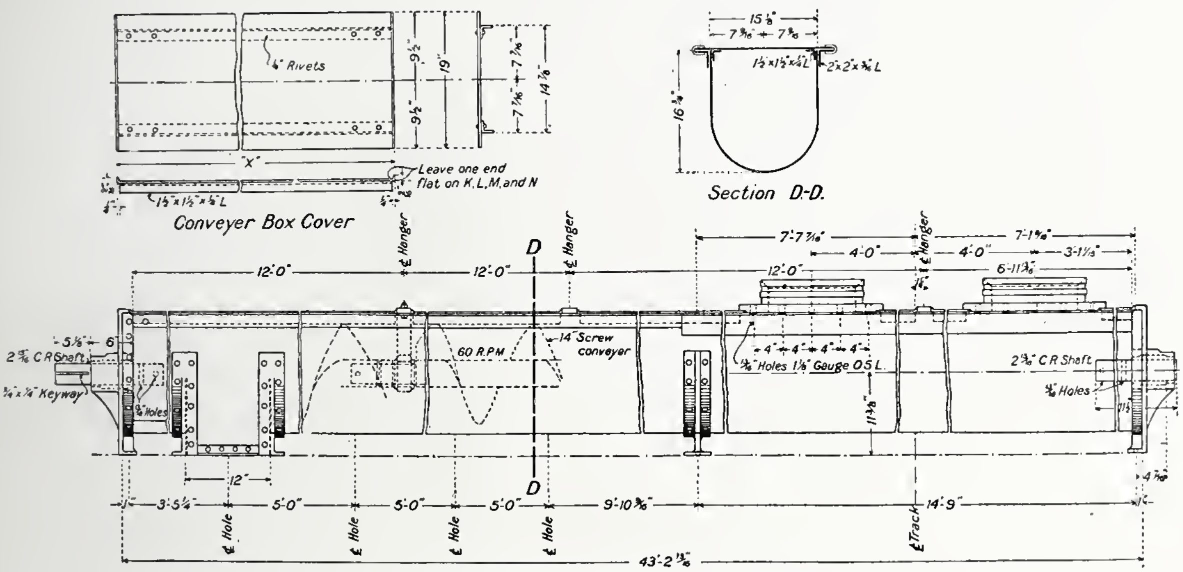


Fig. 90.—Details of 14″ Screw Conveyor.
(*John Blizard.*) (*Department of Mines, Canada.*)

on a small scale. This latter method of fuel delivery is referred to in detail in Chapter XVI, which deals with Small Consumers' Units.

Screw Conveyor System.

Screw Conveyors, Fig. 90, are most in evidence at American works, perhaps because this was the original method used for the purpose. They have their good points, but they are few in comparison with the later systems, which offer additional advantages, especially for "long-distance" transportation.

Screw conveyors have necessarily to be provided with substantial supporting frames, for they must be, as a rule, run overhead along buildings, and where they cross railways or cartways must clear all traffic.

The raising or dropping of conveyor levels is not accomplished without some difficulty, and even on slightly inclined conveyors the pulverised coal will at times flush right through the conveyor worm and pack up at the lower end. Any change in direction usually means a separate conveyor with motor driving gear.

For relatively short runs, such as in a boiler-house plant, or, say, a single range of furnaces, erected in close proximity to the mill-house, it may well be preferable to use elevators and screw conveyors. As to the cost of screw conveyors, a 9 in. conveyor with ground supports will cost about \$8·00 per ft. run. A pipe system with wall supports and valves will cost approximately from \$2·00 to \$3·00 per ft. run.

It is not easy to accurately determine the power absorbed in the transportation of fuel. Under normal working conditions, theoretical calculations can be quite misleading. For an elevator 40 ft. high and 9 in. screw 123 ft. long, the average power recorded at one works is about 7 h.p. for 8 tons of fuel per hour. Of this, 4 h.p. is absorbed by the elevator, leaving 3 h.p. for the 123 ft. run of conveyor. 1 h.p. per 40 ft. run for 8 tons per hour is the usual provision for operating a screw conveyor when the fuel is thoroughly dry. So much depends upon the design of the conveyor and its bearings, and on the quality of the fuel and moisture content, that power figures will vary over fairly wide limits, the actual power required to propel the fluffy, light, dry pulverised fuel being very small. Conveyor screws should be mounted in dust- and weather-tight troughs fitted with sand seal covers.

Indicators should be fitted, in order to give warning when any one conveyor motor cuts out, so that the feeding line will not continue to propel fuel forward into the stationary line. A terminal indicator should also be placed at the end of a line to record any banking up of fuel when demand falls below the rate of supply. Serious damage can be done to screw conveyors by the pressure set up when fuel is fed forward to a dead end. In many cases conveyor covers have been forced off and the pulverised fuel thrown out.

Capacities for pulverised fuel screw conveyors at various speeds are shown in the graph, Fig. 91.

Quigley and Grindle Blowing Tank Systems.

"Air Pressure Transportation" is a method of conveying pulverised coal that has been adopted extensively, with very successful results. Additional patents for improvements and special apparatus necessary for the handling of pulverised coal were taken out in 1916 by Messrs. J. R. MacGarvey, W. Salton and O. L. Haisler, and these patents were acquired by the Quigley Furnace Specialities Co. Present-day development is based upon these patents, and upon the original Duckham method of conveying grain and other fine granular substances by the application of compressed air to closed containers or receptacles for the grain, or other substance to be forced through the supply pipes.

Fig. 94 shows the arrangement of a Quigley pulverised fuel blowing tank erected upon a weighing scale.

The particular form of internal control of fuel delivery consists of a vertical pipe entering at the top of the tank and extending to within a short distance of the bottom, connecting with the transport line. Around this pipe, and of somewhat larger diameter, is a curtain pipe which may be raised or lowered at will by use of a pneumatic cylinder located on the outside of the tank, and operated by the same compressed air as is used for transportation purposes. This curtain pipe is raised

only when coal is to be transported, and is lowered when the required quantity of fuel has been discharged. Hence, by watching the scale, it is possible to stop the flow as soon as the dial indicates a predetermined quantity. The tank rests on scales which accurately weigh the quantity of fuel supplied or withdrawn. A direct

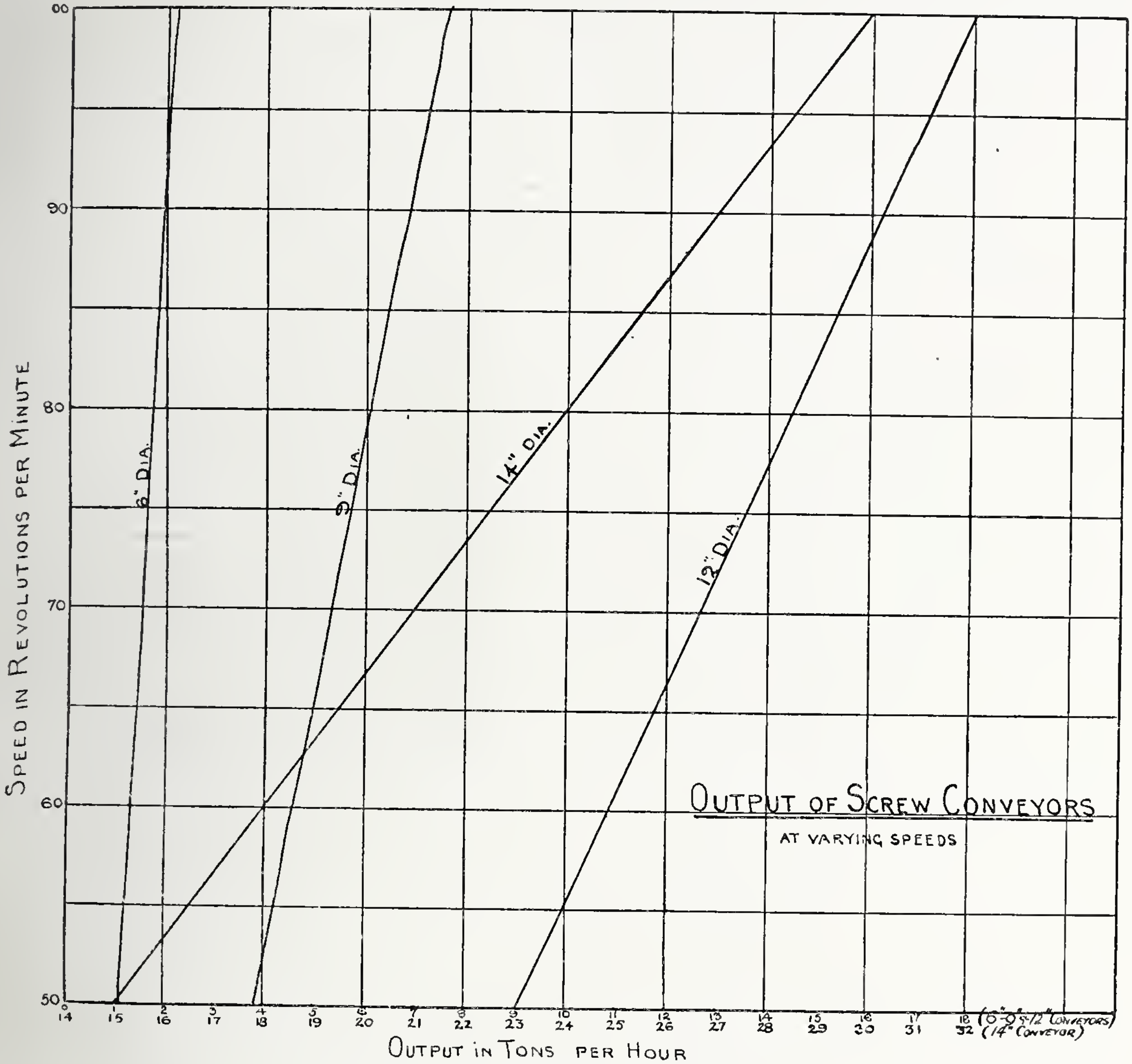


FIG. 91.—Capacities of Screw Conveyors.

reading dial is used to facilitate the reading of the quantity of fuel being transported, by means of the difference in weight before and after transportation.

A compressed air line, with a valve located within easy reach of the operator, admits the air near the top of the bank.

Starting with the coal in the pulverised fuel bin, it is allowed to flow by gravity into the tank when the dust-tight gate and inlet valve are open. The dust-tight gate is located below the bin to control the quantity of coal going to the tank, while

the inlet valve previously mentioned prevents the leakage of air. When the desired quantity of coal as indicated by the weight, read directly from the scale, is deposited in the tank, the dust-tight gate is closed, and then the inlet valve. Compressed air is then admitted. When the desired pressure is reached, the curtain pipe is raised; the shut-off valve in the transport line is then opened, and the coal starts to flow through the transport line.

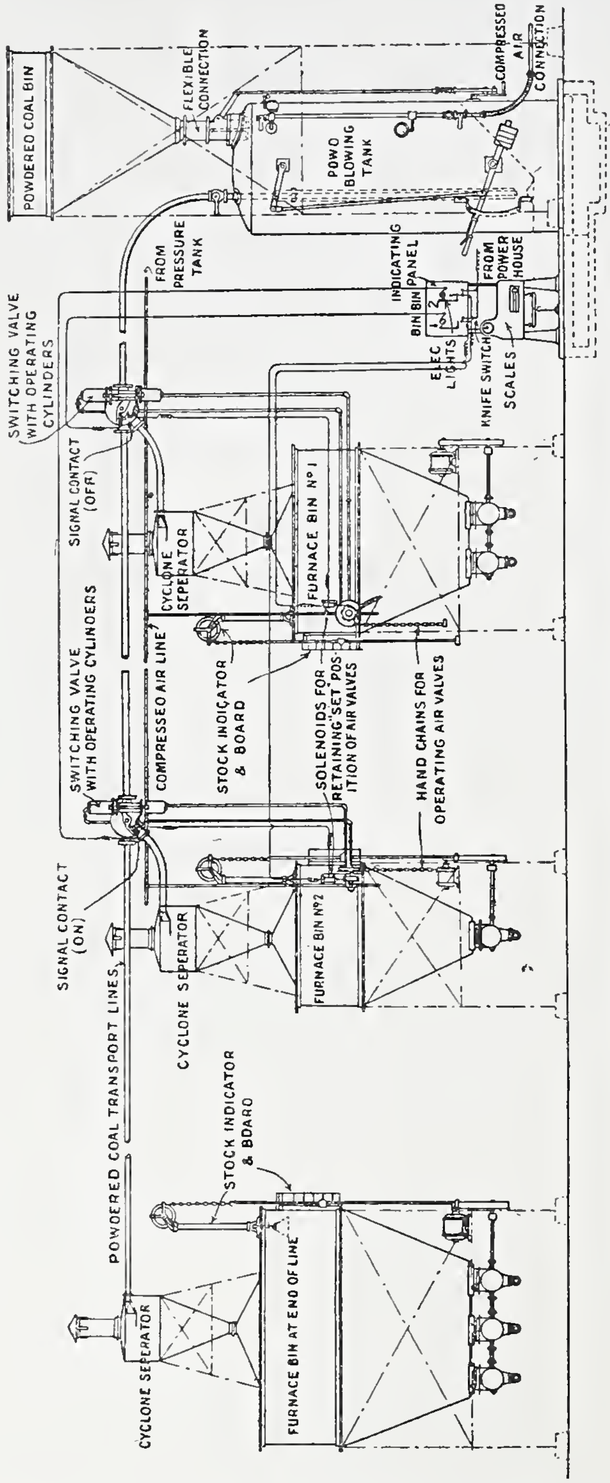


Fig. 92.—Quigley Fuel Transport Line, showing Semi-Automatic Switching Valves.

The pressure on top of the coal, together with the force of air travelling down through the curtain pipe, then mixing with the coal and up through the transport line, is sufficient to transport the coal through the line several thousand feet with but a fraction of the power that would be required if this coal were to be forced through the pipe by pressure alone. There is an action which causes the slugs of coal to be followed by air, which facilitates transportation of the coal through the pipe.

An important feature of this system is that the air required is less than 1 % of that necessary to produce a combustible mixture.

It is not necessary to discharge the entire quantity of coal in the tank at any one time; in fact, the tank once filled can supply several small bins without being refilled. When the curtain pipe is lowered, no more coal can pass up through the transport pipe, but the air is short circuited and the transport line is thereby cleared.

Compressed air at 30 to 60 lb. per sq. in. is used, the pressure depending upon size of delivery pipes and distance of transportation.

Through a 4 in. pipe line, 140 tons of fuel per hour have been delivered to a

distance of 1000 ft., the power absorbed being 450 h.p. hours or 3·2 h.p. hours per ton of fuel delivered over this distance.

It is stated that with an improved type of equipment the power can be reduced to about $2\frac{1}{2}$ h.p. hours per ton for delivery of fuel 1000 ft. from the source of supply.

It is usual to estimate that 1 cu. ft. of free air compressed to 30 lb. per sq. in. will be required for 2 to 3 lb. of pulverised fuel for distances up to 1000 ft.

The power absorbed by the Quigley System can be further based upon actual records taken for delivery of fuel through 3500 ft. of 4 in. pipe. On a 600 ft. length of this supply pipe, 4 tons of pulverised coal have been transported in 5 minutes, with the motor air compressor maintaining the line pressure at 50 lb. per sq. in., the power required being 50 h.p.

600 ft. × 4 tons = 2400 ton ft. or 480 ton ft. per minute with an expenditure in power of 50 h.p., so 480/50 = 9·6 ton ft. per minute per 1 h.p., or approximately 10 h.p. per ton per minute per 100 ft. distance. Some additional information for power consumption with this system is given at p. 217.

A difficulty experienced with this system of conveying fuel is the occasional sending of too much fuel. If delivery is continued after a bin is full, there is every possibility of bursting the cyclone separator into which the fuel is delivered.

Fig. 92 shows the powdered coal storage bin, the blowing tank and the transport pipe line. Semi-automatic switch valves are shown for diverting the coal-dust to the supply bins at the furnaces.

It will be noticed that every furnace bin is fitted with a cyclone coal-dust delivery separator.

The air used in the propulsion of the fuel from the blowing tank at the mill-house escapes through the vent pipe attached to the cyclone separator.

(In this manner it is claimed that coal-dust could be readily conveyed into the bunker cylinders of a ship in dock, or by the use of special coaling vessels, and pulverised coal could be supplied to ships lying in harbour or at sea.)

From the " Blowing Tanks " the coal-dust travels through ordinary 3 in. or 4 in. screwed piping, fitted with normal bends and fixed overhead or underground, with just the same convenience as the running or laying of water or gas pipes.

To guard against stoppage due to moisture in the coal or condensation within the conveying pipes, a small companion pipe with tappings into the coal-delivery pipe is provided. By this means compressed air can at any time be supplied through the companion pipe to the tappings or " bleeders," and any packing of coal in a section of the line be broken up and forced through the furnace bin.

A very ingenious accessory to this system has been evolved by W. O. Renkin, engineer to the Quigley Organisation, for the semi-automatic feeding of coal-dust to any number of bins throughout the works. In order to accomplish this, switch valves are placed at each turn from the main supply pipe to a furnace bin. Each switch valve is fitted with a spring release and solenoid controlled catch. Each solenoid is operated by a push button at the mill-house.

The mill attendant goes the round of the bins at the furnaces, notes the quantity required at each bin, sets the switch valve to " supply," and on completion of his

round returns to his blowing tanks. From these he sends the quantity required to bin No. 1; when the amount is registered on the scale dial he clears the coal from the supply pipe into No. 1 furnace bin, then he presses No. 1 solenoid valve release button and despatches the required quantity of coal dust to No. 3 bin, and so on. In this way the attendant can supply any desired quantities of coal direct from the mill-house.

Delivery pipes should be erected with a fall to a draining-off point, for otherwise an accumulation of water and fuel will freeze in cold climates and the application of high-pressure compressed air to a blocked section of supply pipe may not break

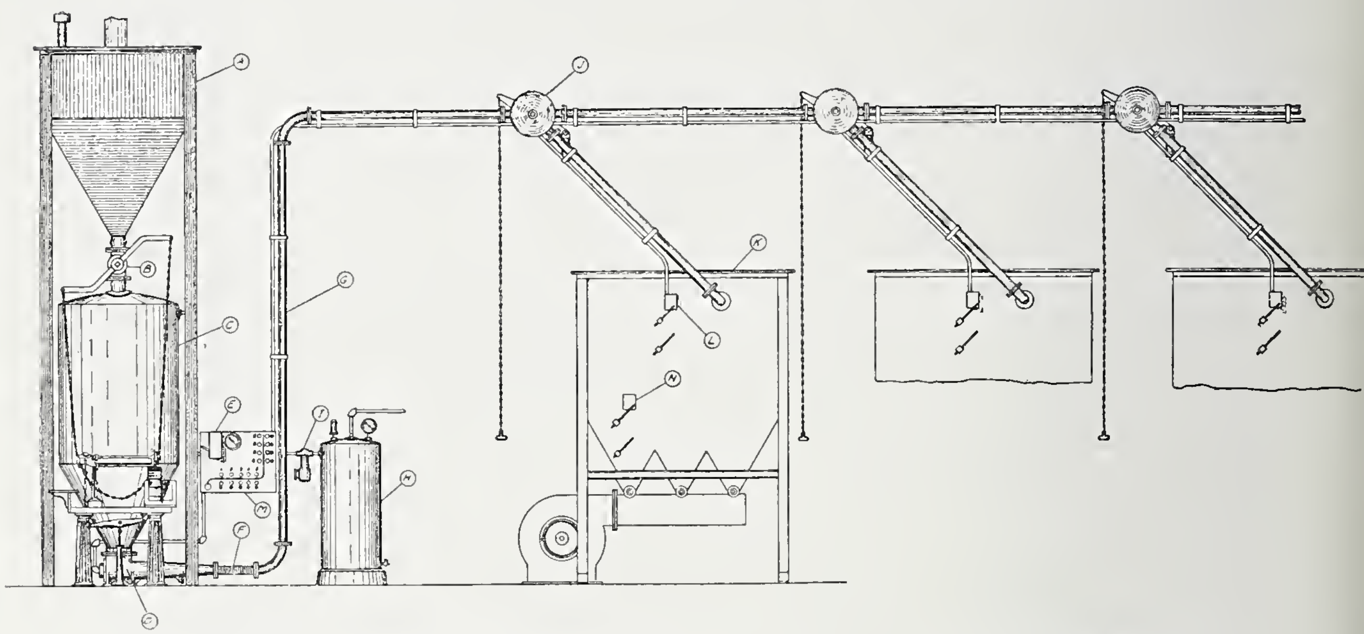


Fig. 93.—Diagram of Grindle Pneumatic Fuel Conveying System. (*The Grindle Fuel Equipment Co.*)

A Fuel storage bunker with air-tight valve *B* and flexible connection to pressure tank *C* on weighing scale. *D* special feeder supplied with compressed air through valve *E*. Aerated fuel passes through flexible coupling *F* to supply line *G*. *H* compressed air primary dryer. *I* secondary moisture separator on compressed air supply. *J* switch valves. *K* furnace fuel bins. *L* overflow indicator automatically controlling switch valve *J*. *M* signal board. *N* low level indicator. Operation of *L* shows white light on *M* and operation of *N* a red light.

up the solidified water and fuel mixture. It has been found that, during cold weather, moisture which has condensed inside the pipe, during the operation of fuel supply, has accumulated at a low point in the line, becoming frozen into a solid block of ice.

The Grindle pulverised coal low pressure compressed-air conveyor system is illustrated in Fig. 93.

Figs. 95 and 96 show the receiver tank, weighing scales, compressed air reservoir, and signal and operating control board.

Fig. 97 shows the special feeder below the fuel tank to which compressed air is admitted for forcing the fuel through the delivery pipes. The capacities of Grindle conveyor units and the quantity and pressure of air necessary for this purpose are :—

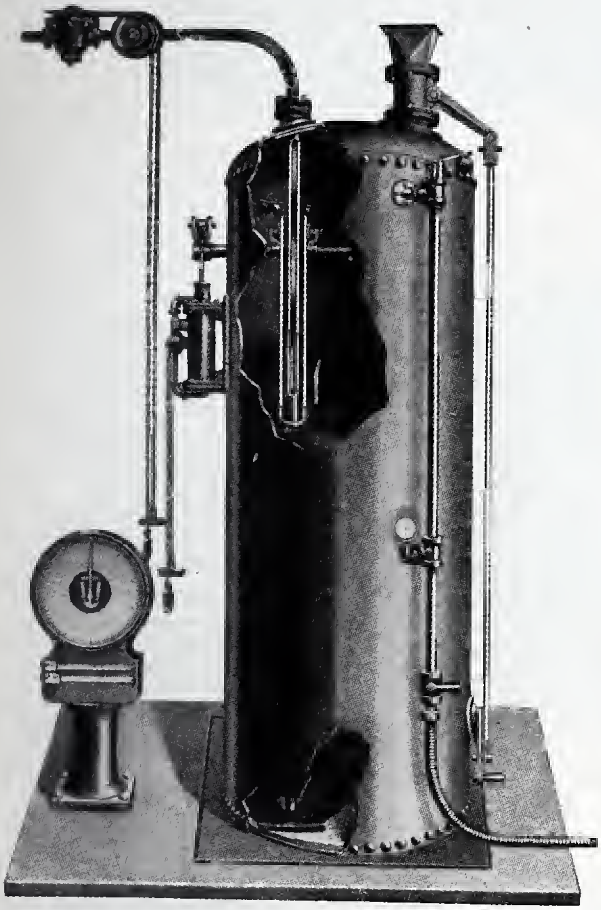


Fig. 94.—Quigley Blowing Tank for Transportation of Pulverised Fuel by Air Pressure, showing Fuel Supply Recorder.

Quigley Fuel Systems, Inc.]

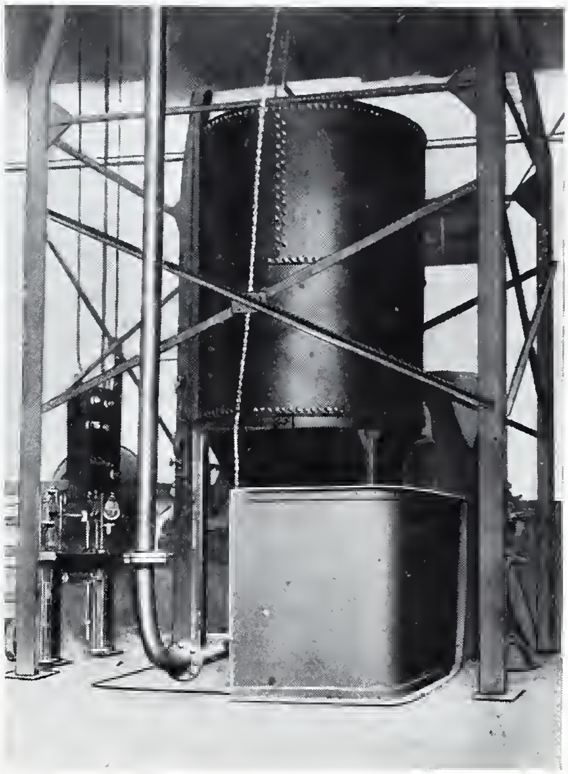


Fig. 95.—Grindle Pneumatic Fuel-conveying System, showing Pressure Tank on Weigh Scales, Signal Board, and Delivery Pipe.

Grindle Fuel Equipment Co.]

[*To face p.* 212.

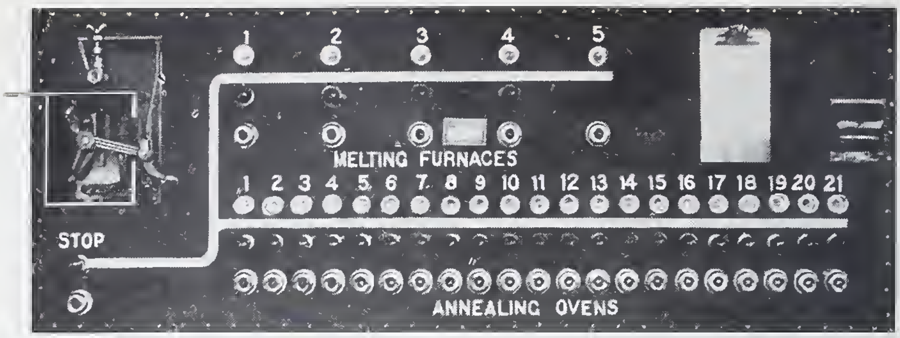


FIG. 96.—GRINDLE PNEUMATIC FUEL CONVEYING SIGNAL BOARD.
The Grindle Fuel Equipment Co.]

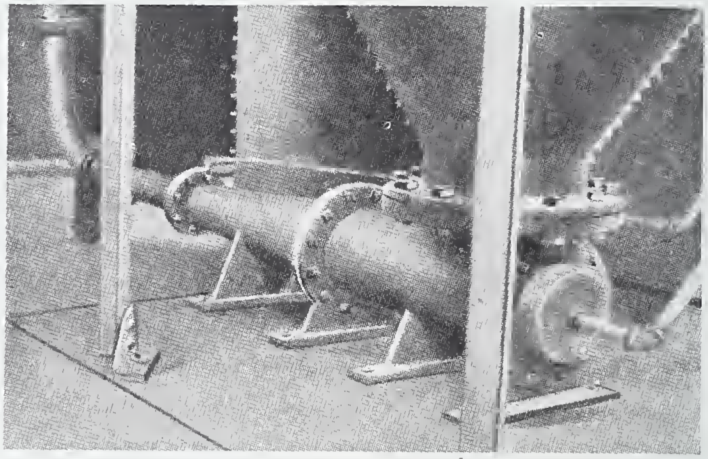


FIG. 97.—GRINDLE PNEUMATIC FEEDER FOR FUEL-CONVEYING SYSTEM.
The Grindle Fuel Equipment Co.]

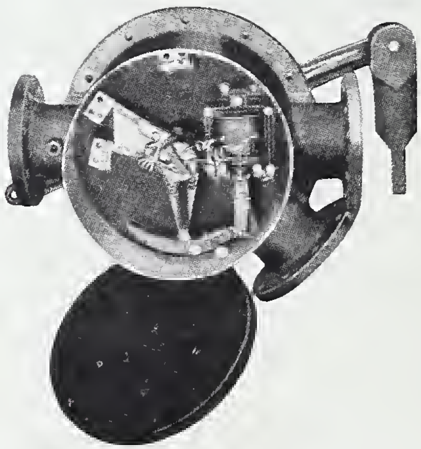


FIG. 98.—GRINDLE SOLENOID CONTROLLED SWITCH VALVE.
The Grindle Fuel Equipment Co.]

	10 lb. air supply pressure per sq. in.	Size of delivery pipe. (inches.)	Volume of free air per min. (cu. ft.)
Capacity of unit in lb. of coal per min.	250 lb.	2	45
	600 ,,	3	105
	1000 ,,	4	175

It has been found that increased delivery capacity can be obtained by increasing the pressure on the air supply, but with the relatively low pressure of only 10 lb. per sq. in. adopted for standard practice, all general requirements are met without recourse to higher pressures, which would necessitate a more expensive air compressor plant. The volume of air required for relatively short distances is thus about 400 cu. ft. per ton of coal conveyed.

The Grindle switch valves, Fig. 98, on fuel-supply mains are clearly shown in the illustrations, and are of the automatic type, being moved into the open or closed positions by electric solenoid control, actuated by contact switch and circuit wiring.

Also for this system a method of electric control of branch valves has been worked out so that the demand for fuel can be seen at the pulveriser mill plant, and fuel despatched as required.

A standard control board showing indicator signal devices for a Grindle system is illustrated in Fig. 112.

Careful attention should be given to the working details of a pneumatic delivery system, the more so when high pressure compressed air is to be used, otherwise there may be a needless and heavy loss of power per ton of fuel conveyed. An example of this has been demonstrated at a works at which a Grindle air-pressure system has been installed.

With a 60-ton powdered coal storage hopper and a 5-ton weighing tank and scale, coal is transported at the rate of approximately 20 tons (2000 lb. per ton) per hour through a group of pipe lines of total length 3000 ft., the longest line being approximately 1300 ft., and is distributed to some forty different hoppers. The fuel is despatched at the rate of half a ton per minute through a 5 in. line, the amount of free air required per ton of coal delivered being approximately 700 cu. ft.

Previous to the erection of this equipment, an older combination of pneumatic transport system and screw conveyor was in use, and the power taken to operate this combination was between five and six times the power that is now used, as much as 4000 cu. ft. of free air per ton of fuel delivered being previously required for the air transport system replaced.

The Holbeck or Bonnot Air-Mixture System.

The "Air Mixture" System, as first adopted by Holbeck, after whom the "Holbeck," or Bonnot, equipment has been named, was the first practical method to be extensively used for the conveying of pulverised coal mixed with air and for transporting the fuel over long distances.

An essential for the satisfactory operation of a fuel and air mixture conveying

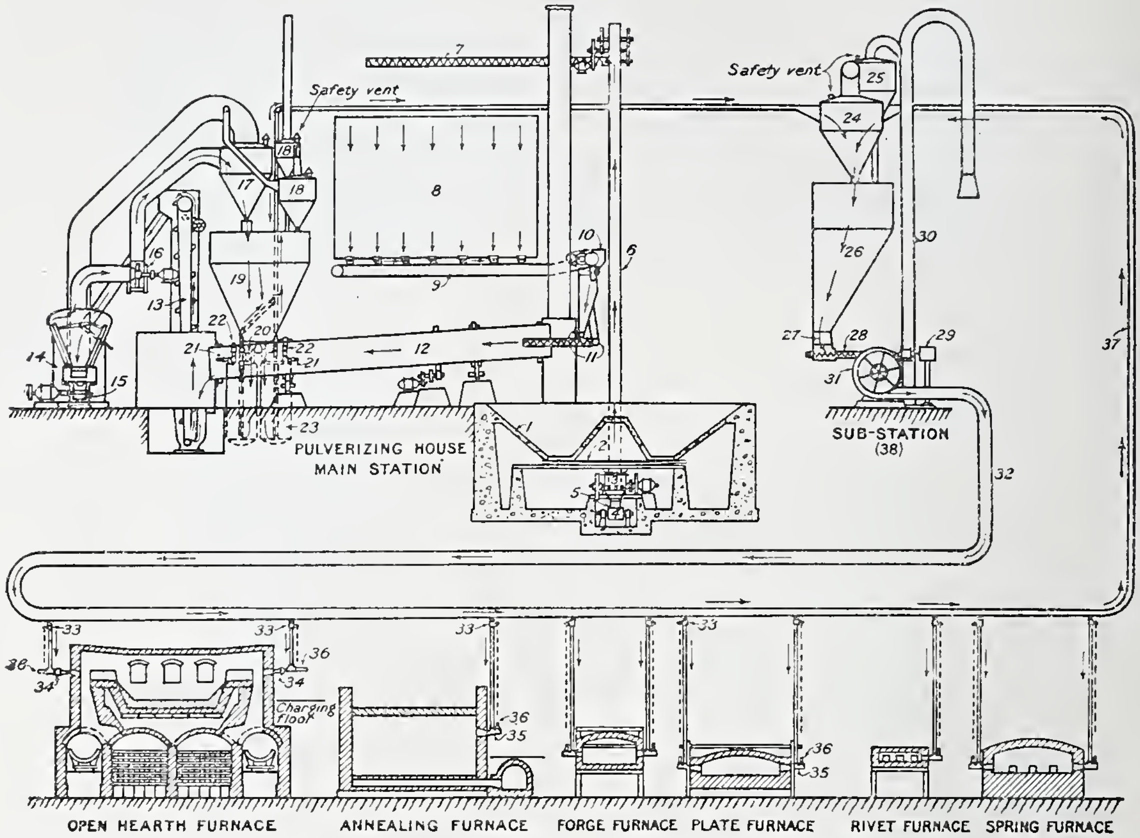


Fig. 99.—Holbeck Fuel Distributing System (*The Bonnot Company*), showing Sub-station method of Fuel Supply.

(*John Blizard*) (*Department of Mines, Canada.*)

1. Track hopper.
2. Reciprocating feeder to feed coal from the track hopper to coal crusher.
3. Coal crusher to receive coal from the reciprocating feeder.
4. Belt conveyer to deliver coal from the coal crusher to the bucket elevator.
5. Stationary magnetic separator over the belt.
6. Centrifugal discharge bucket elevator.
7. Distributing screw conveyor with casing and flights, to receive coal from the elevator and distribute it in the coal bunker.
8. 3-Ton coal bunker divided into two parts, so as to store two kinds of coal.
9. Belt conveyor to deliver coal to the automatic scale.
10. Automatic scale.
11. Screw conveyors, to receive coal from automatic scale, and deliver same to coal dryer.
12. Rotary dryer.
13. Centrifugal discharge bucket elevator to deliver coal from dryer to dried coal storage bin.
14. 5-Ton dried coal storage bin.
15. Bonnot coal pulverisers, complete with vacuum separator.
16. Mill exhauster to exhaust pulverised coal from the separator and deliver same to the collector.
17. Pulverised coal collector above 25-ton bin.
18. Auxiliary pulverised coal collectors.
19. Pulverised coal storage bin.
20. Special outlet castings with valves to let pulverised coal into ejector tanks.
21. Compressed air line.
22. Vent line.
23. Ejector, which delivers pulverised coal to the various sub-stations through a 3-inch pipe line by means of compressed air.
24. Pulverised coal collector, at sub-station, which receives pulverised coal from the ejector.
25. Auxiliary collector.
26. 25-Ton capacity pulverised coal storage bin.
27. Special outlet casting to support feed screw.
28. Special feed screw, for feeding coal to the distributing system.

system is fine and uniform pulverisation of the fuel. A mixture of coarse and fine product cannot be maintained in perfect suspension for any one initial air velocity; the coarse particles must separate out as the velocity diminishes due to drop on the line, or service requirements, and it is naturally an impossibility to alter the dimensions of the conveying pipe, as service conditions vary from hour to hour. It is, therefore, apparent that the grinding of fuel for this method of supply should receive special attention, and be accomplished in particularly well designed mills for the production of a maximum proportion of fine and uniform product.

The mixture travels through the supply pipes to the furnaces under a pressure of some ten ounces per sq. in., and at a rate of 5000 ft. per minute (roughly one mile per minute).

Any portion of this air and coal-dust mixture not used in the furnaces is returned by the loop system, shown in Fig. 99, to the cyclone separator, wherein the coal dust is collected and the air with which it is mixed is extracted and discharged into the atmosphere. The coal dust thus recovered is returned to the storage bin for remixing with air by means of the fuel-supply fan. In any plant, there must necessarily be times when only a few furnaces are in operation, yet a heavy supply of coal dust with this system must be maintained, otherwise the "richness" of mixture is impaired and velocity diminishes. The system would then cease to function properly and there would be danger of explosion in the mains. The amount of power wasted in operating the mixing fans and booster fans under such circumstances is a serious consideration. As a means of regulating, as far as possible, the relative proportion of pulverised fuel to air taken in by the mixing fan, a special automatic regulating device is used. The action of this regulator is dependent upon the rate at which air is supplied to the fan, and as the demand increases, so the air-control cylinder valve opens, and, by means of a self-adjusting device, the speed of the screw feeding the coal-dust (see Fig. 57) into the mixing fan is varied.

It would appear that further improvements of a type more in keeping with coal-milling machinery have yet to be made in connection with this automatic control

---

29. Automatic regulator which automatically controls the speed of the variable speed motor that drives the feed screw, thus to feed the pulverised coal in proportion to the amount of air flowing through the distributing system.
30. Vent pipe with top bent down to prevent its acting as a flue and thus producing suction on the system which might draw flame into the pulverised coal main if blower should be stopped for any reason.
31. High pressure distributing blower, to furnish the necessary air for distributing the pulverised coal to the furnaces.
32. Pulverised coal main to furnaees with branch lines to burners.
33. Valve for regulating the flow of pulverised coal to the burner.
34. Special burner for open-hearth furnaces.
35. Cast-iron water-cooled burner.
36. Air blast line to deliver secondary air to form the proper mixture for burning pulverised coal.
37. Return main to take surplus pulverised coal and air mixture to pulverised coal collector which deposits the unused coal into 25-ton pulverised coal storage bin.
38. At McKees Rocks plant there are five sub-stations, which are substantially the same as shown, one for annealing furnaces at foundry and one for open-hearth furnaces at foundry, one for forge plant, spring and rivet shops, one for miscellaneous order department and one for plate heating furnaces in pressing department. The mixture of air and pulverised coal in coal distributing main is 1 lb. of pulverised eoal to 63 cubic feet of air. The mixture of air and pulverised coal when burning in furnaces is 1 lb. of pulverised coal to about 230 cubic feet of air.

(From *Iron Age*, Vol. 102, No. 12.)

apparatus. The idea is very well conceived, but the actual instrument is somewhat too complicated and too delicate to withstand the test of the rough-and-ready conditions attaching to a pulverised fuel preparation and supply plant.

The supply of mixed air and coal dust for furnaces is tapped off the main and led to the burners through ordinary branch pipes, in a similar manner to the supply of gas, and this is shown in Fig. 100.

Branch control shutters or valves must be placed close up against the supply main, in order to prevent, as far as possible, the settlement of coal dust at these points. This cannot be entirely prevented, and under certain conditions the danger of spontaneous combustion in the small quantities of fuel lodged above a branch valve may be serious, if, owing to the presence of glowing coal-dust, the mixture becomes ignited. The secondary air for combustion is delivered through a main air trunk to the burners in the usual manner.

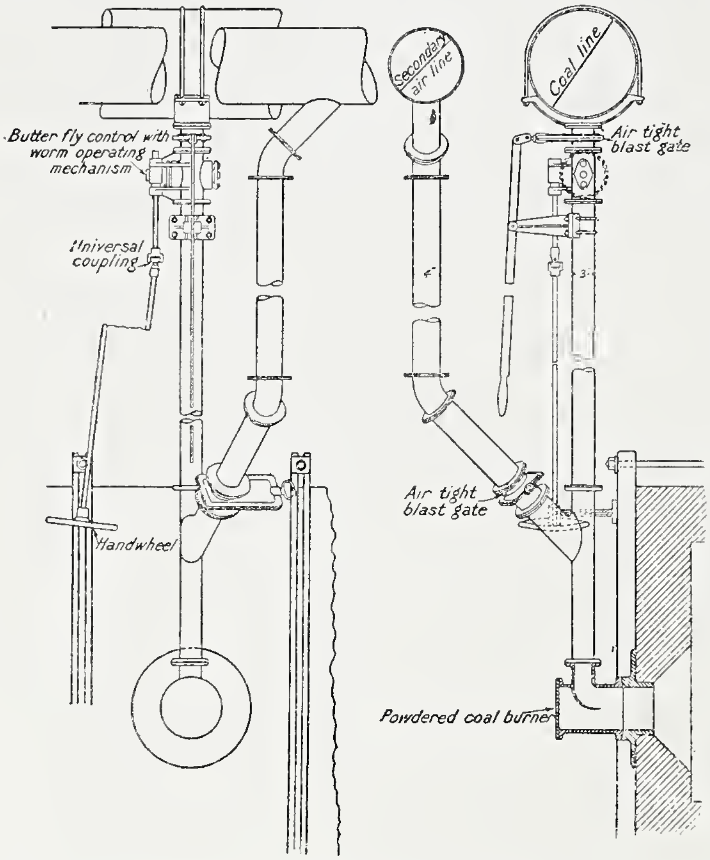


FIG. 100.—Fuel and Air Supply Control Valves for Holbeck System. (*The Bonnot Company.*)
(*John Blizard.*) (*Department of Mines, Canada.*)

For heavy duty, where large quantities of coal-dust are required throughout a works, the supply piping becomes of considerable dimensions, and the mixed coal-dust and air must be maintained at an exceptionally high velocity, in order to eliminate the possibility of back-firing, and also to carry the coarser particles of coal-dust in proper suspension.

Although explosion doors and non-return valves have been fitted by users of this system, some serious accidents have occurred, and many of the original air-mixture conveyor systems have lately been removed. Furthermore, with any system in which the coal-dust is mixed with air in a high-velocity fan, there is considerable wear and tear of ordinary steel fan blades and casings. To overcome this difficulty as far as possible, mixing fans have to be provided with heavy cast-iron casings, and the fan blades should be fitted with reinforced wearing plates of hardened steel.

A comparison between the power required for pulverising coal, and delivery by the air-pressure " Blowing Tank " system to furnace bins, and delivery by the " Air Mixture " method through loop supply mains, has been worked out for three plants

of $2\frac{1}{2}$, 5 and 10 tons per hour capacity. In each case local conditions, such as length of delivery pipes, location and number of furnaces, have been assumed to be approximately the same, and the figures given below are based as far as possible upon actual motor readings in existing plants.

Capacity of Plant. Tons per Hour.	Mill-House Plant & Air-Mixture System. (Continuous Conveying System).			Mill-House Plant and Blowing Tank System. (Burner Feed Controllers Continuous Conveying System Intermittent.)				
	H.p. readings of motors per ton of coal per hour.	Total h.p. of motors installed.	Total h.p. hours.	H.p. readings of motors per ton of coal per hour.	Total h.p. of motors installed.	H.p. hours on continuous work.	H.p. hours on intermittent work.	Total h.p. hours.
$2\frac{1}{2}$	98	250	4,900	52	167	2,600	200	2,800
5	75	370	7,500	39	203	3,900	400	4,300
10	52	525	10,400	26	319	5,200	800	6,000

The great difference between the total h.p. of motors required for the two systems is apparent. It must also be remembered that the power absorbed for the conveying of fuel by the " Air-Mixture " system is continuous, whereas in the " Blowing Tank " System the motors operating the air compressors are run intermittently in order to build up the supply of compressed air held in the high-pressure air containers; the screw feeders at the burners alone absorb continuous power.

The figures quoted above include the power used in the mill-house, and in order to compare the power required for the two systems for fuel delivery only, the following computations have been made, the assumption being that 200 tons of fuel are to be pulverised and burned per 24 hours, the fuel being supplied in each case to a maximum distance of approximately 1200 ft.

	" Air-Mixture " System.	" Blowing Tank " System.
Pressure per sq. in. on primary conveying air	12 oz.	60 lb.
H.p. of motors—primary motor	150 } continuous	90 { intermittent
H.p. of motors—booster motor	100 } (air used)	(air lost)
Pressure per sq. in. on primary air at burners	12 oz.	6 oz.
Pressure per sq. in. on secondary air at burners	6 oz.	$1\frac{1}{2}$ oz.
Quantity of primary air cu. ft. per min.	20,000 [1]	65,000
Quantity of secondary air cu. ft. per min.	40,000	45,500
H.p. of motors for combustion air and for controllers (" Blowing Tank " System)	100 (12 oz.)	120 (6 and $1\frac{1}{2}$ oz.)
Total h.p. of motors for conveying and burning	350	210
Total h.p. hours for ditto	8400	say 4800
H.p. hours per ton of coal burned	42	24
Total motor h.p. per ton of coal burned in 24 hours, for conveying and burning only	1·75	1·02

[1] Make up for primary air lost in return cyclone separator.

The approximate power consumption for the " Air-Mixture " system in excess of that required for the " Blowing Tank " System is, therefore, in the region of 75 %.

Bergman and Covert Air-Mixture Systems.

L. H. Bergman advocates the bin system of fuel storage at the furnaces or

boilers, but for certain special work he supplies an air and coal-dust mixture system, a diagram of which is shown in Fig. 101. This mixture system differs from the "Holbeck" in that the surplus fuel and air are returned to a cyclone separator, the coal-dust being extracted therein, but instead of being deposited on the top of the pulverised fuel in the main bin, as in the Holbeck system, it is delivered to the coal feed screw, and must be the first fuel to be remixed with the air. This is an important point, for it prevents the accumulation of "coarse" fuel in a layer over the pulverised coal in the main supply bin.

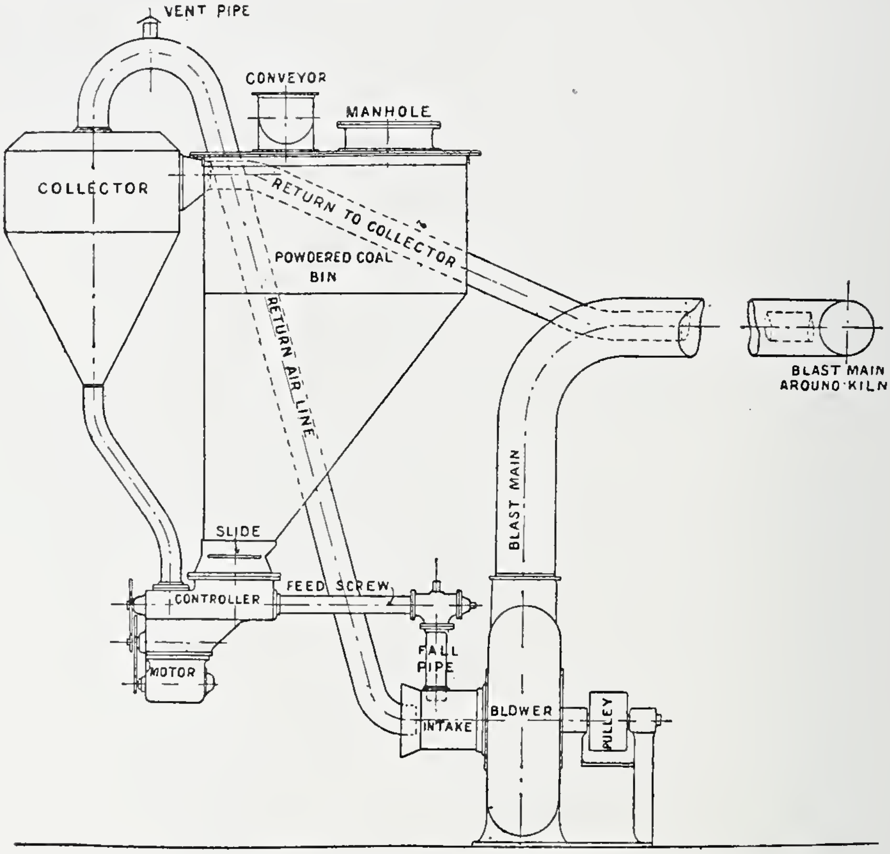


Fig. 101.—Bergman Fuel and Air-Mixture Supply System.

Another feature of the Bergman air and coal-dust mixture system is the return of the fine dust and air extracted from the unused coal direct to the air mixing fan, instead of exhausting this fine dust and air to the atmosphere as in other systems.

This equipment forms a self-contained plant suitable for a small furnace shop. Such an arrangement can often be used to advantage in conjunction with the usual bin system for other parts of the works, and forms a supplementary system for use under special circumstances. The powdered coal is delivered to the fuel bunker by screw conveyor, and the mixing operation is effected through the medium of the rotary fan.

Covert aimed at supplying specially designed apparatus to suit each individual

application, and to this end the continuous coal-dust and air mixture system shown in Fig. 102 was devised.

This again is unlike the pioneer " Holbeck " system in that the return of the surplus mixture is taken direct to the mixing fan inlet, there being, therefore, little waste power in dealing with this surplus fuel and air. Any deficiency is drawn from the mixing chamber at the top of the main fuel tank. Coal-dust is injected into this mixing chamber by means of a small quantity of compressed air, and the actual supply of coal-dust and air is regulated by the diaphragm control shown at the top of the make-up pipe.

One or two of the more important points claimed for this continuous air and coal-dust distributing system are :—

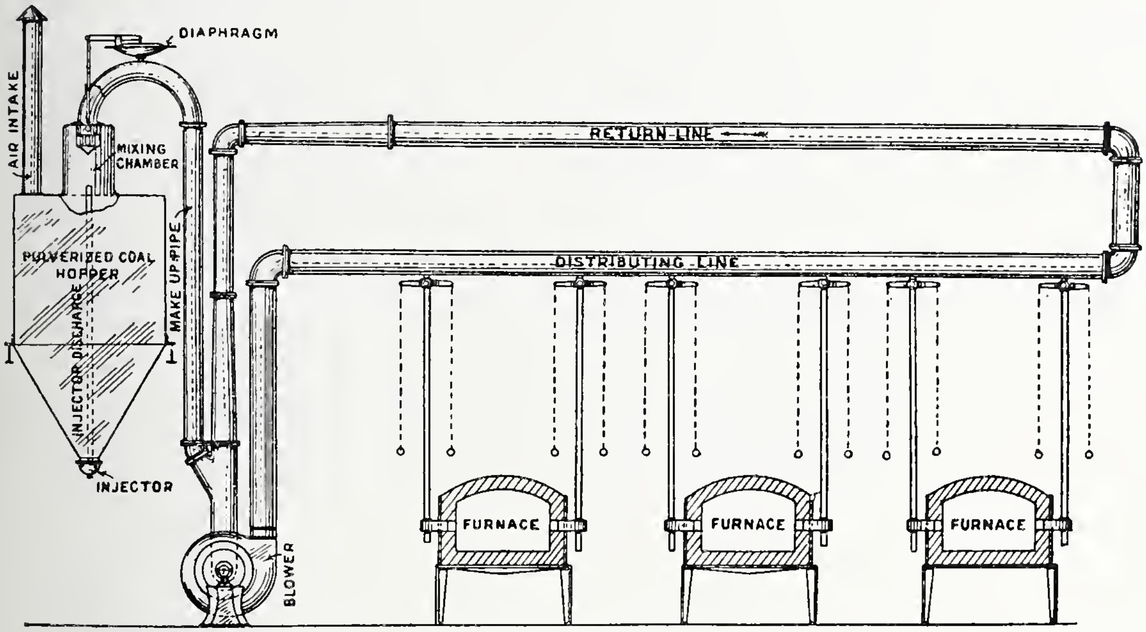


FIG. 102.—Covert Air and Fuel Mixture Supply System. (*Heyl and Patterson Co.*)

(*a*) The coal-dust is not separated out after having once been mixed with air, and is, therefore, not subjected to a semi-oxidising process more than once. This practically removes the difficulty experienced with other air and coal-dust mixture systems, as applied to low-temperature furnaces, in which it is sometimes impossible to burn partially oxidised coal-dust.

(*b*) In other systems, the larger particles of coal-dust, due to their momentum and inertia, pass the branch openings to the furnaces and are returned to the main fuel bin; in consequence, a series of strata of coarse coal is often present in bins connected with such systems. In the Covert system all coal once taken from the bin is in constant circulation until burned, any coarse particles being ultimately split up in the mixing fan.

(*c*) The mixture is supplied at constant velocity, and is, therefore, at constant richness, no matter how many furnaces may be working at one time.

Covert advocated the transportation of pulverised fuel in bulk, either by

means of the screw conveyor, or by means of compressed air. Covert, however, followed the general practice of delivering fuel over long distances by compressed air to be subsequently conveyed to furnaces by the air-mixture method. At one plant visited by the author coal-dust was transported by the latter method over a distance of 1500 ft. through 1782 ft. of 3-in. pipe (allowing for bends and detours) to a sub-station. Coal is delivered to these sub-station containers by compressed air, and is thereafter mixed with air, and so circulated to a number of small furnaces.

The Fuller-Kinyon Pumping System.

The pumping of pulverised coal as a method of transporting fuel can be accomplished with the Fuller-Kinyon pumping equipment, Fig. 104, or the "Pulco," Figs. 108 and 109.

In order to obtain the best results, and if power consumption is to be reduced to the minimum, the conveyor conduit should be made of galvanised iron pipe with all bends of large radius, and should be galvanised *after* bending. It is also very desirable to avoid abrupt vertical lifts; this is the more essential close to the pump. Vertical heights can be reached without trouble, or objectionable power consumption, if the rise is made on an easy incline. All joints should be so made that the ends of the pipe sections butt together in the barrel connector, and all pipe ends should be carefully reamed out smooth before assembly.

The advantages claimed for a pumping system are :—

(1) Moderate first cost. The simplicity of the entire pulverised material conveying system, such as that of the Fuller-Kinyon description, permits of a low first cost, which is considerably lower than that of any other pulverised material conveying system.

(2) The fact that there is but one moving part in connection with the pump referred to, namely, a 6 in. helicoid screw or worm attached to a heavy shaft, the worm flights being of extra heavy steel double posted and rivetted to a $2\frac{1}{2}$ in. diameter cold rolled steel shaft mounted in bearings with large wearing surfaces, ensures long life and freedom from mishap with consequent delays.

(3) The small amount of air introduced to aerate, or change the pulverised material to a semi-fluid state, so that it can be pumped, is so slight that no provision is necessary for separating the coal and air at the point of delivery. The coal and air can be discharged into the receiver bin just as delivery is made for water. A vent pipe on the bin is all that is needed for release of the air as it gradually leaves the mass of coal. This does away with the necessity of cyclone separators and dust collectors, which are not only an expense, but require additional head room within the buildings.

(4) The fact that the coal passes through air-tight sheet iron conduits from mill or from coal bins direct to the pump, and through iron or steel screwed and jointed pipe from the pump to the point of delivery, ensures absolute freedom from dust.

(5) The cost of erection is reasonable, there being no necessity for heavy trestle supports or run-ways, as for screw conveyors. A single line of conveyor conduit

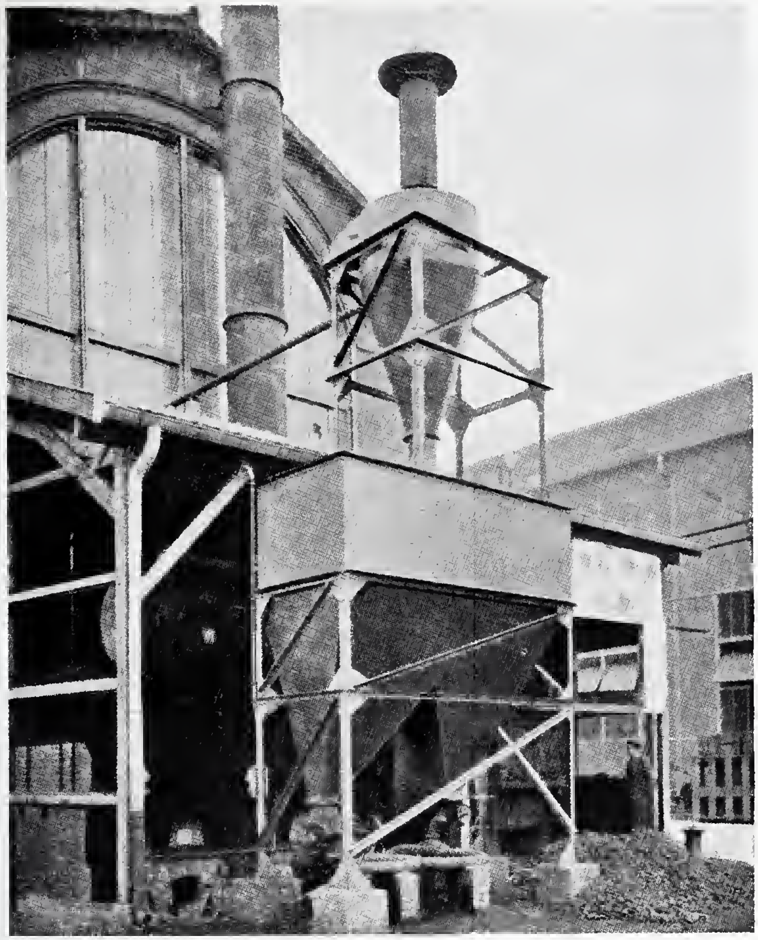


Fig. 103.—Pulverised Fuel Delivery Pipe, Cyclone Separator, and Fuel Bins (Simon-Carves System).

Simon-Carves Ltd.]

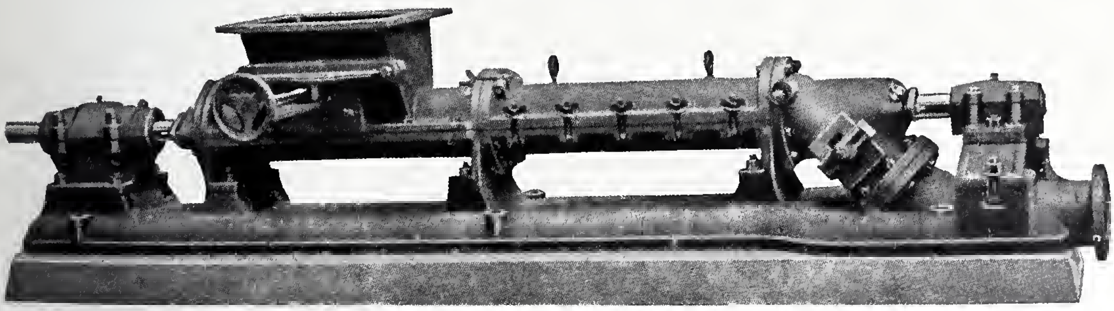


Fig. 104.—The Fuller-Kinyon Pulverised Fuel Pump.

The Fuller Engineering Co.] [*The Fuller Lehigh Co.*

[*To face p.* 220.

supported in a similar manner to water or gas piping completes the system. A secondary pipe-blow through line connected at intervals to the fuel pipe, often used in connection with pressed air " blowing " systems, is not, as a rule, necessary. The coal, when aerated, assumes a semi-fluid condition, and this permits of the coal being forced through a conduit having a large number of long radius bends without the likelihood of coal " packing."

When fuel is liable to contain much moisture, as in the case of stored lignite, it may then be advisable to instal a parallel compressed-air pipe having connections to the fuel pipe, so that blockages can be dislodged.

The air required for " aerating " the pulverised coal is about 1 cu. ft. at 4 lb. per sq. in. pressure per 30 lb. of coal conveyed. Ratings for long distances are given in a later paragraph.

Power consumption varies so much according to conditions, such as the size of pipe line, type of bends, and length of line, etc., that no really definite or fixed data can be given. An average figure for power derived from a number of records is 0·4 h.p. per 1000 lb. per hour, per 100 ft. of pipe line, up to, say, 500 ft.

On a short pipe line, 100 ft. or so, this figure may rise to about 1·3 h.p., whereas on lines of 500 to 1500 ft. it may fall to 0·3 h.p. per 1000 lb. per hour, per 100 ft. of pipe. The figures quoted include the power necessary for driving the air compressor for the air supply, and allow only for one rising bend at the pump, the height of delivery being about 40 ft. Further power records are given below.

At one installation, a 6 in. dia. Fuller-Kinyon pump, as shown in diagram Fig. 105, is in operation, taking delivery of pulverised coal at the rate of 6 tons per hour, and transporting the fuel 150 ft. through ordinary 4 in. dia. screwed iron pipe to a storage bin. The pump runs at 720 r.p.m., and is driven by a 20 h.p. motor. The whole of this fuel is then delivered by means of another Fuller-Kinyon pump through similar piping to furnaces 250 ft. away, the pump taking in this instance approximately the same power as for the shorter distance.

In comparison with this system, at the same installation an ordinary 9 in. steel flight screw conveyor is in use for conveying pulverised coal at the rate of 10 tons per hour some 500 ft., the conveyor screw running at 75 r.p.m. and taking 15 h.p. for this duty. The power absorbed by the screw conveyor is, therefore, about 1 h.p. per 333 ft. tons per hour, and, for driving the two Fuller-Kinyon pumps, about 1 h.p. is expended, respectively, for 45 and 75 ft. tons per hour.

At the Lebanon works of the Bethlehem Steel Company two pumps are installed, each capable of delivering 7 tons of fuel per hour through 800 ft. of piping, with a 35 ft. lift. For this duty the power taken by either pump is 24 h.p.

When installing fuel pumps ample motor power must be provided to take care of the initial torque when starting up with a full line, for then about double the normal running power is required.

It will be seen that the total actual power taken by a pumping equipment is greatly in excess of that necessary to operate straight line screw conveyors, but the many advantages of small pipe line delivery outweigh the disadvantages of costly trestle construction for screw conveyors, and the difficulty of leading off screw conveyors at varying levels and in different directions.

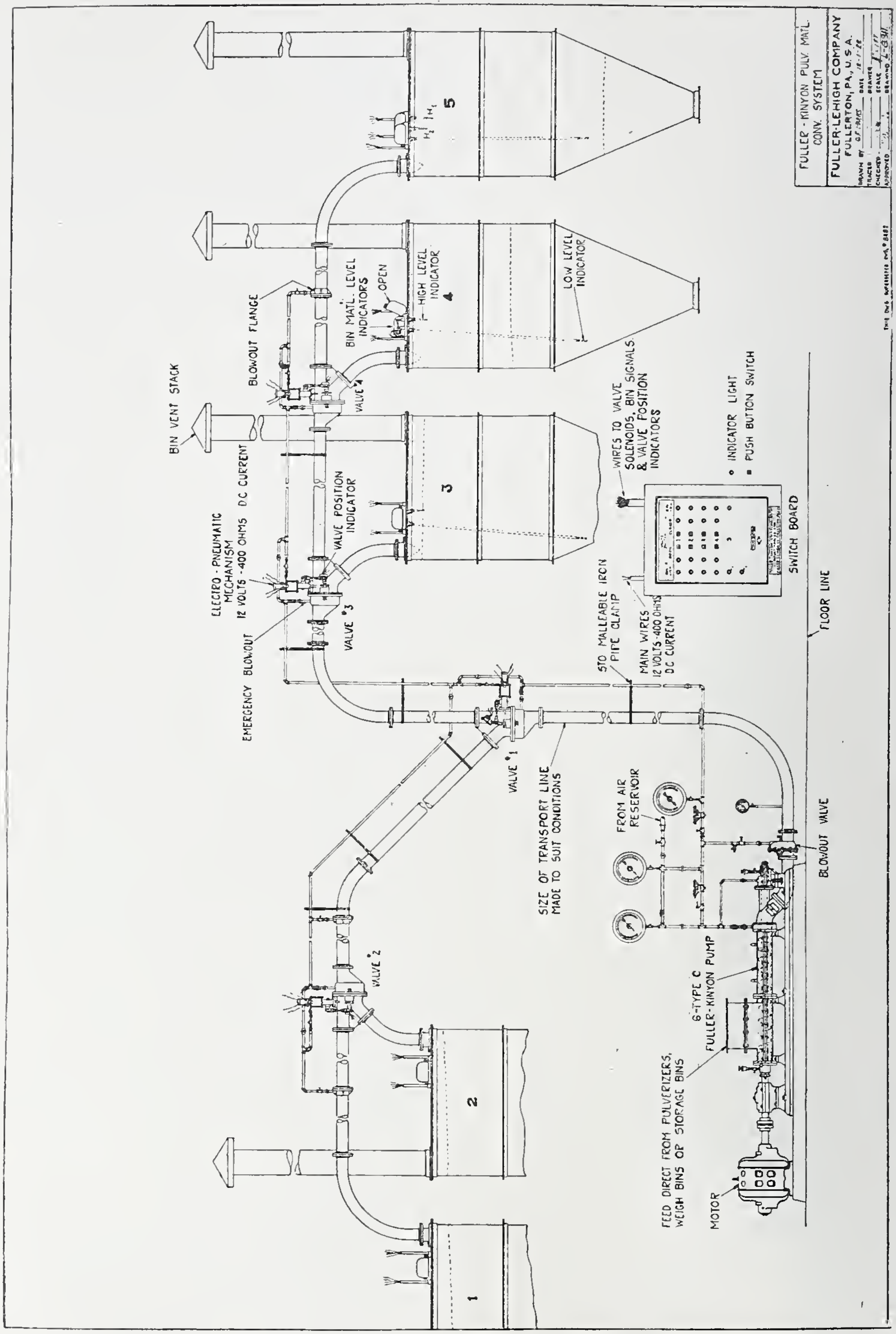


FIG. 105.—Arrangement of Fuller-Kinyon Pulverised Fuel-Delivery Pump, showing Five Furnace Supply Bins and Switch Valves. (The Fuller Engineering Co.). (*The Fuller-Lehigh Company.*)

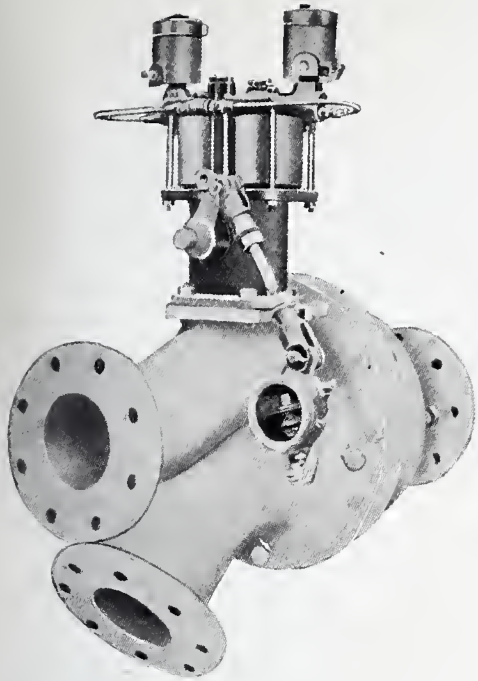


FIG. 106.—AUTOMATIC SWITCH VALVE FOR FULLER-KINYON FUEL SUPPLY SYSTEM.

The Fuller Engineering Co.] [*The Fuller Lehigh Co.*

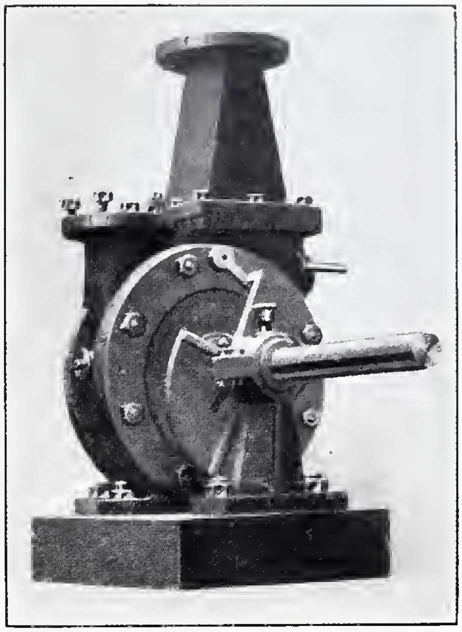


FIG. 108.—THE PULCO PULVERISED FUEL DELIVERY PUMP.

Pulco Supplies, Ltd.]

FIG. 107.—MOTOR-DRIVEN FULLER-KINYON FUEL DELIVERY PUMP, SHOWING FUEL STORAGE BUNKERS AND DELIVERY PIPES.

The Fuller Engineering Co.] [*The Fuller Lehigh Co.*

[*To face p.* 222.

The full rated capacity of a 6 in. Fuller-Kinyon pump is about 8 tons of pulverised coal per hour. This quantity could be delivered through a 4 in. pipe, say, 500 ft. in length with a rise of 20 to 25 ft. with the pump driven by a 25 h.p. motor at 750 r.p.m. For aerating this amount of fuel for this length of delivery, 75 cu. ft. of free air compressed to from 30 to 35 lb. per sq. in. would be required.

It would appear from information available that the most economical working conditions for this size of pump are obtained when pumping to a maximum range of about 1000 ft. in one stage, at the rate of 6 tons of coal per hour, through a 4 in. dia. pipe line. A 3 in. dia. pipe line was used in earlier installations, but the reduction in power for driving the pump when a 4 in. dia. pipe line was subsequently used more than compensated for the extra initial cost of the larger diameter pipe.

Wherever possible, the motor for driving the pump should be directly connected through a flexible coupling, although belt or chain drives can be used, and, further, the pump and air compressor should be independently driven, so as to permit independent operation when starting up.

The highest vertical lift so far reported in practice is about 60 ft., but it has not been proved that this figure is the maximum lift possible, or that the pump would not function satisfactorily when delivering fuel to higher points.

The most economical air pressure to be employed under given conditions has also not been firmly established ; it has, however, been found that any appreciable increase in length of pipe line necessitates an increase of the air pressure at the pump. Pressures of the order of 20 lb. per sq. in. at the pump have been used on short lines of 80 to 150 ft., whilst pressures of about 50 lb. per sq. in. have been found necessary for pipe lines 1000 ft. long.

The air used for transmission of the fuel is mixed with the pulverised coal at the delivery outlet of the pump, and the amount of air so used appears to be about 0·3 cu. ft. of free air per pound of coal conveyed, or 300 cu. ft. for every 1000 lb.

Pulverised coal conveyed in this manner has a very special formation at the outflow of the pipe line. No special air separator is required at the discharge end of the line, or on the bins into which the coal is to be discharged. The air used for conveying the fuel permeates the mass to such an extent that the discharge is of a smooth creamy nature, and it is only necessary to provide a hole in the top of the bin with a vent pipe from 6 to 10 ft. high in order to prevent the escape of dust when a bin is being filled. As the coal falls into the bin a gradual settlement takes place, the air which impregnates the fuel is gradually displaced, and escapes by the vent pipe without carrying off any of the fine particles of coal. A Fuller fuel switch valve is shown in Fig. 106 and a view of pumps connected to fuel storage bins is given in Fig. 107.

The Pulco Pump.

Another type of fuel pump is the Pulco pump. This is illustrated in Figs. 108 and 109. The following brief description is based upon information published in *The Engineer*, March 3rd, 1922.

As will be seen from the illustrations, the pump is extremely simple in form, and has only two interior moving parts, (*a*) the elliptical rotor, (*b*) a flap which separates the inlet from the discharge branch. The flap is actuated by an external cam and roller, which can be seen in the half-tone engraving. This type of pump is not, of course, altogether novel, but it is claimed that its use for such a purpose is comparatively new.

The general arrangement of a plant for pumping powders up to distances of 200 ft. and through any reasonable lift is shown in the illustration. The material is delivered into the hopper in the framework, and is prevented from packing together into a solid mass by means of an agitator driven off the pump shaft. The pump sucks the powder out of the hopper by an inverted syphon, and a certain proportion of air is mixed with it in the pump. The extent of this addition is

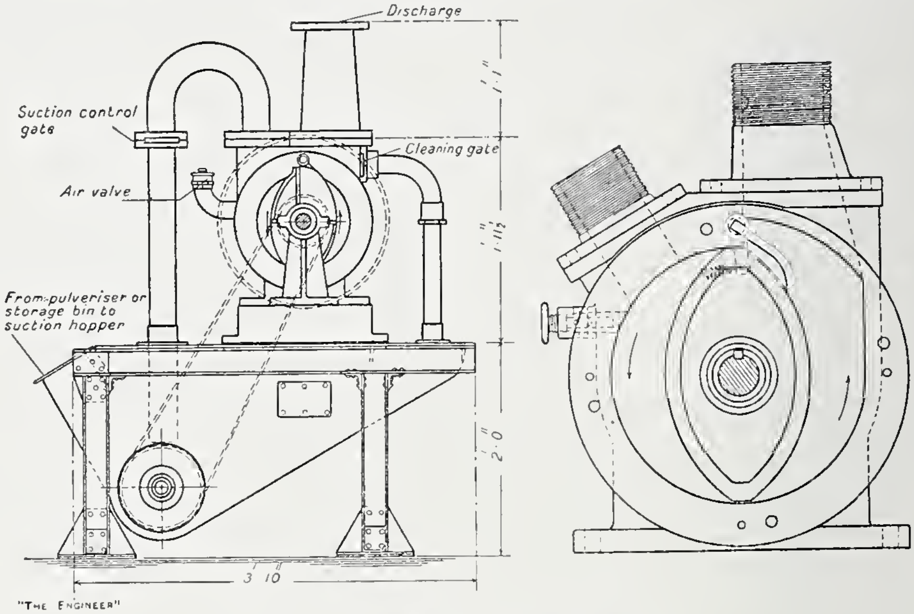


Fig. 109.—Diagram of Pulco Pump.

regulated by a snifting valve, which can be seen near the pump inlet. The pump is driven at a speed of about 150 revolutions per minute. The Pulco pump, like the Fuller-Kinyon pump, should be equally suitable for use in place of bucket elevators for raising pulverised fuel to bins, and for supply of fuel through distributing pipes.

The following figures refer to actual tests carried out with a Pulco pulverised coal pump—size, 4 in. delivery, 3 in. suction. Owing to restricted head-room the total head was only 16 ft. Speed of pump, 150 revolutions per minute; fineness of coal, 90 % through a 100-mesh screen; weight of fuel per cu. ft., 39 lb.; moisture content, 7 %; pounds of coal pumped per minute, 200; vacuum under working conditions, 8 in. of mercury; vacuum with closed inlet, 22 in. of mercury; volumetric efficiency, 44 %; electrical h.p., 2·4.

In the Fuller-Kinyon pump it has been found that in course of time the horizontal shaft of the screw becomes severely cut away by the pulverised coal in passing

across the screw shaft to the pump outlet. A particularly valuable featurc of the Pulco pump is the natural flow of the material through the pump chamber, and its tangential discharge to the supply pipe.

Measuring the Quantity of Pulverised Fuel Delivered.

When fuel is delivered to furnace bins by means of the blowing tank system, measurement of coal sent to any one bin can be ascertained by the weighing scale readings. In other cases there is no means of telling how much coal is transmitted, or burned. A measure of the coal burned at a furnace is taken in proportion to the number of revolutions of the feeder screw, which can be calibrated.

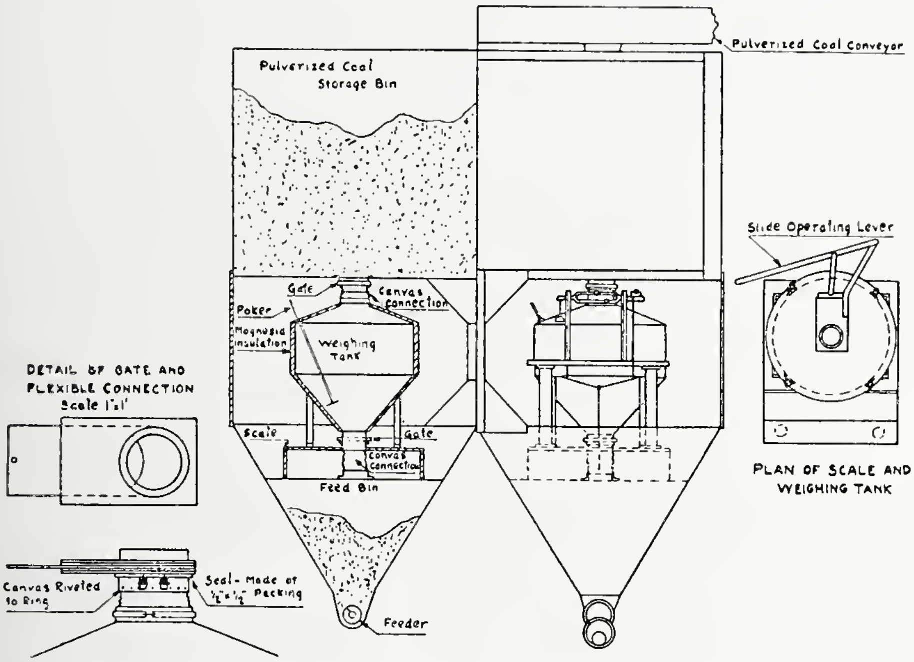


FIG. 110.—Arrangement of Pulverised Fuel Automatic Weighing Scales at Milwaukee Generating Station.

(*H. D. Savage.*) (*American Iron & Steel Institute Paper, May* 1921.)

The only other manner in which the weight of fuel can be recorded is by means of automatic weighing scales inserted in the circuit at the mill-house, or below the storage bin at a sub-station. Automatic scales at the mill-house can be inserted either at the dry coal discharge or at the outlet of the pulverised coal hopper. Such an arrangement at the Milwaukee Power House is shown in Fig. 110, and Fig. 111 illustrates an automatic weighing machine inserted in the pulverised fuel supply at a furnace.

A multiple recording instrument for recording the quantities or rate of flow of steam, air, pulverised coal, and the temperature of flue gases is supplied by the Bailey Motor Company of Cleveland, Ohio, U.S.A.

As fitted up for giving these various readings in connection with a pulverised fuel-fired steam boiler, as at Milwaukee, the instrument is shown in Fig. 111*a*.

It is stated that in sueh an application the pulverised fuel and products of

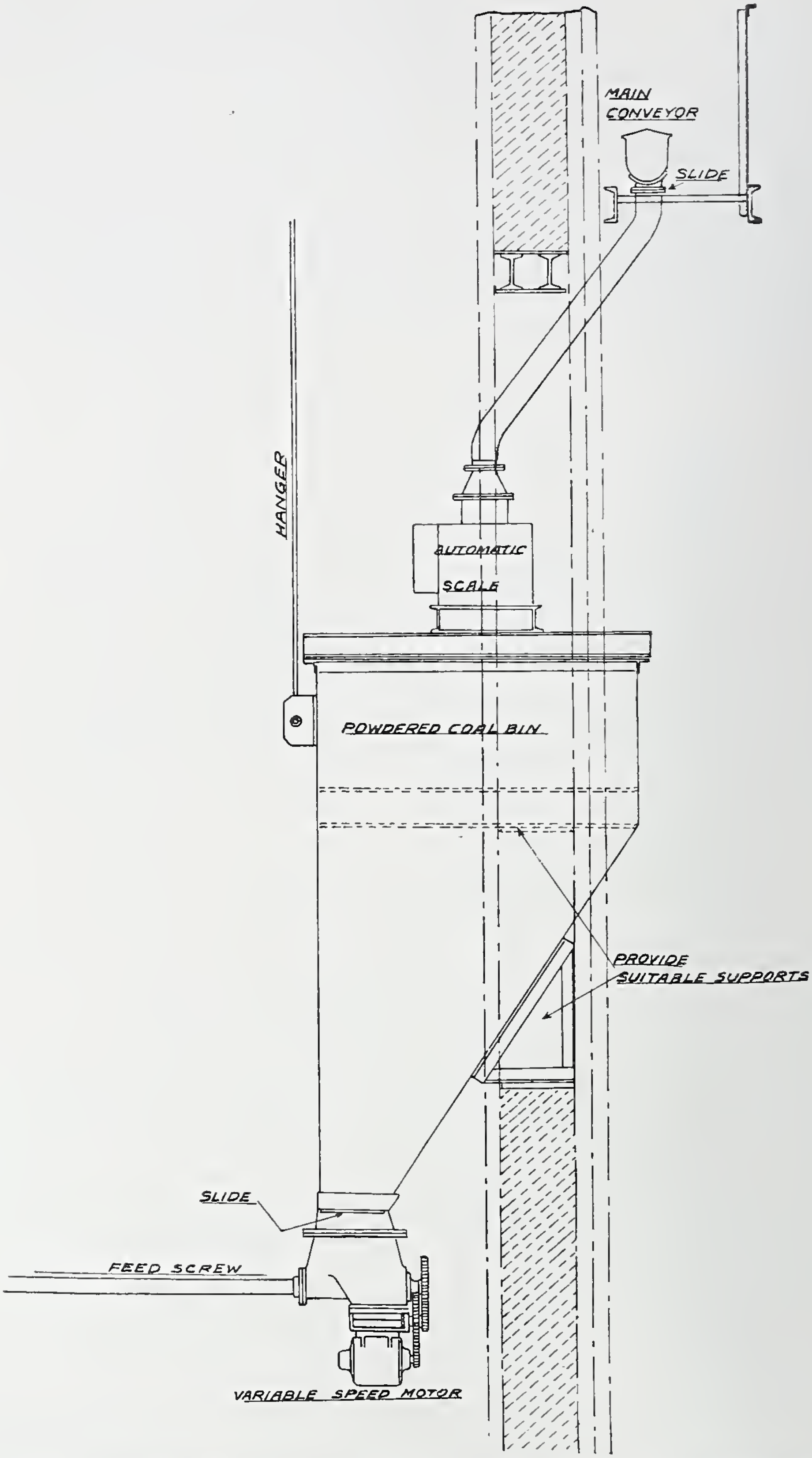


Fig. 111.—Automatic Fuel Weighing Scales at Furnace Supply Bin. (*Bergman System.*)

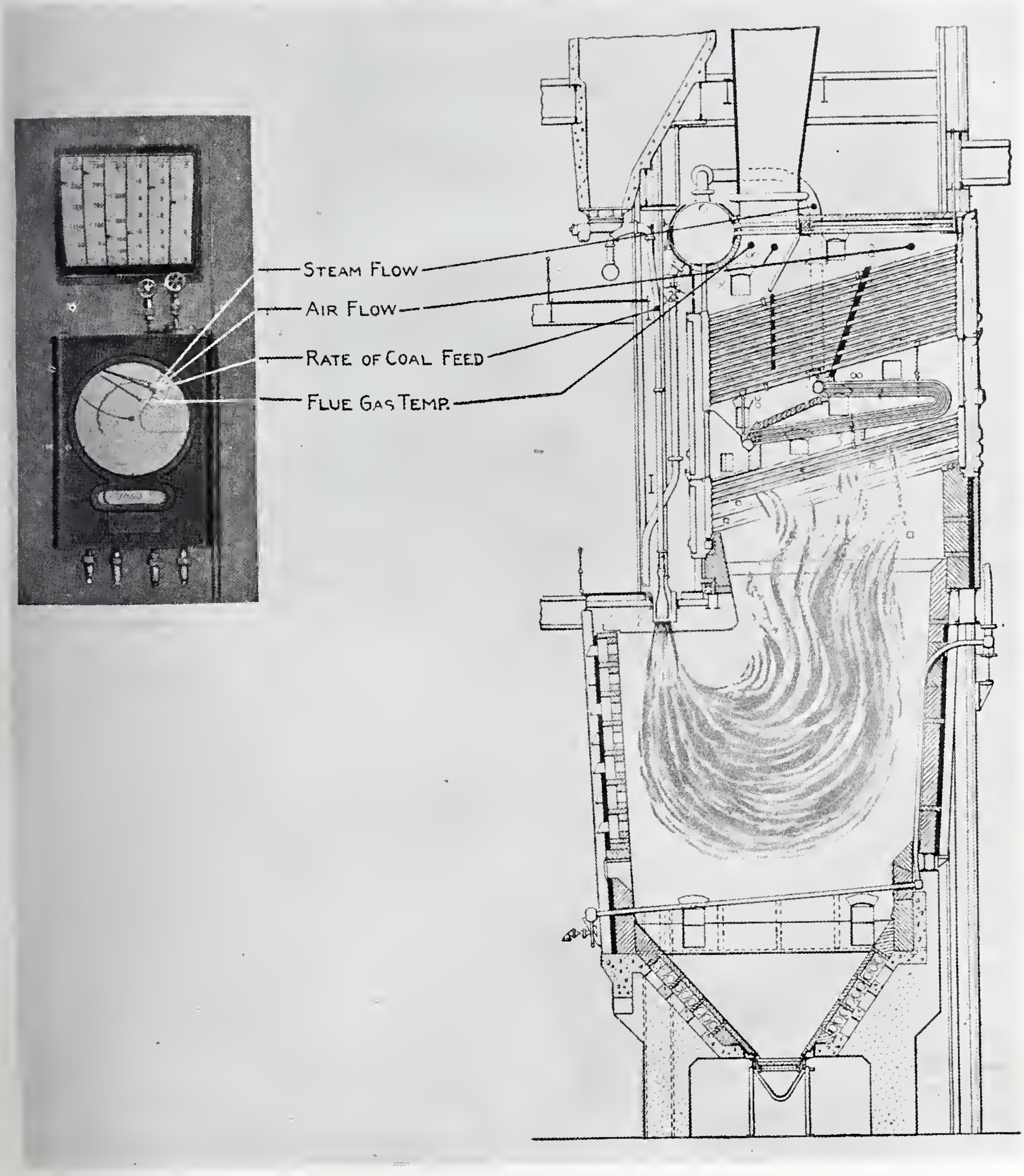


FIG. 111*a*.—BAILEY RECORDING METER FOR PULVERISED FUEL AND AIR SUPPLIES; FLUE GAS TEMPERATURE AND STEAM FLOW.

Bailey Meter Co., Cleveland, U.S.A.]

[*To face p.* 226.

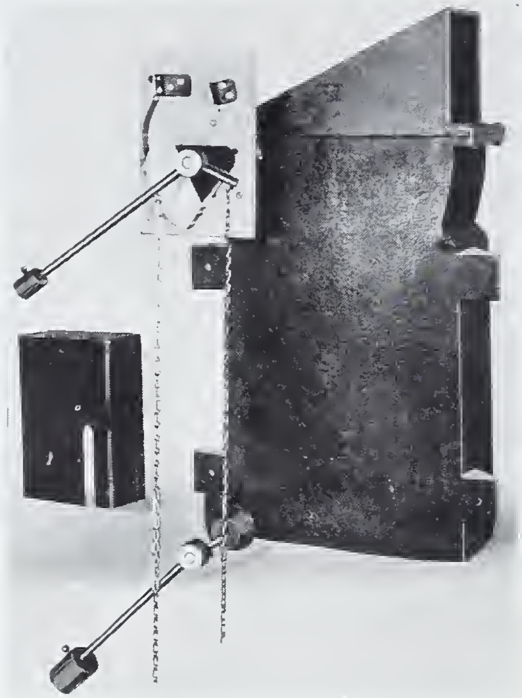


FIG. 112.—GRINDLE FUEL BIN INDICATOR.

The Grindle Fuel Equipment Co.]

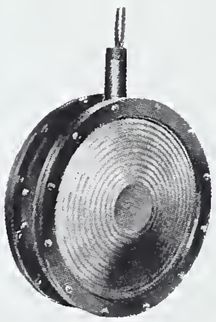


FIG. 113.—FULLER DIAPHRAGM FUEL BIN INDICATOR.

The Fuller Engineering Co.]

combustion in the firing chamber pass through the latter in about three seconds and the air flow meter responds to every change in the rate of supply so that the establishment of correct combustion conditions can be adjusted according to the dial readings of this instrument.

There is always difficulty in obtaining an accurate or even an approximate measure of pulverised coal in a supply bin. The fuel is of such light nature that the surface level cannot well be ascertained by any float or plate let down on to the fuel. Gauge glass indicators are, of course, useless with a dark powdery substance such as pulverised coal.

A novel type of fuel indicator is that supplied with the Grindle system, and shown in Fig. 112. This consists of attachments fitted to the inside of a fuel bin at the top and bottom. By this means an electric contact is closed when the bin becomes full, and the lower contact operates at any desired point to indicate the emptying of the bin. By making and breaking these contacts the supply valves of a Grindle conveyor system are automatically operated, and signals are made on the mill-house board showing that fuel is wanted at the furnace bins nearing depletion.

Another type of pulverised fuel indicator has been introduced by the Fuller Engineering Company, and is shown in Figs. 113 and 114. The indicator, Fig. 113, consists of a cylindrical casting fitted with two sensitive diaphragms. Two indicators are used on each bin, Fig. 114, one at the top and one at the bottom. The pressure of fuel against the side of the top indieator makes interior electric contact, and warns the operator when the bin is full. This warning can be transmitted back to the point of supply. Similarly, but with a reversal of action, the bottom indicator effects electric contact when the pressure of fuel is taken off the sides of the indicator, *i. e.* when the bin empties, and notification of the fact is transmitted accordingly.

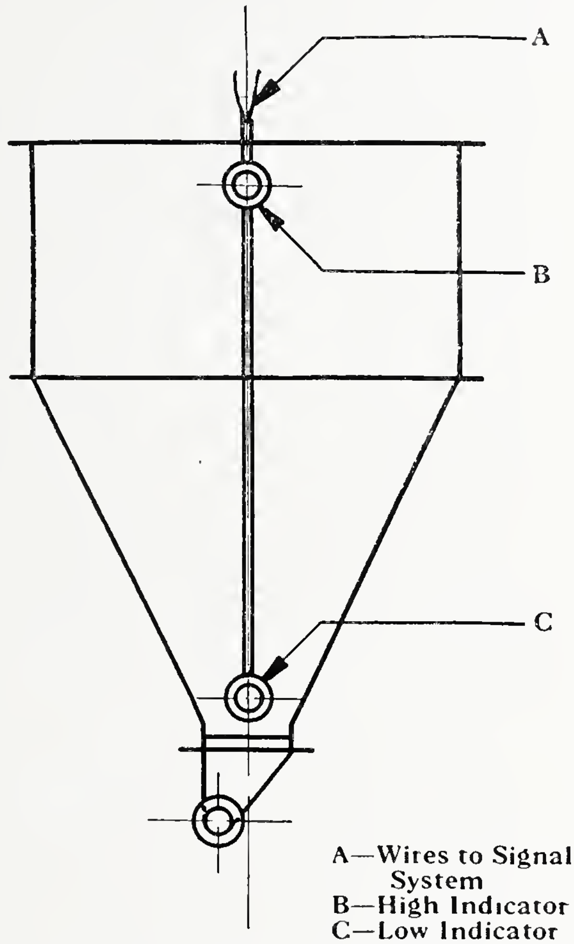


FIG. 114.—Diagram of Fuller Pulverised Fuel Bin "Full" and "Empty" Indicators.

A Quigley type of bin indicator is shown in Fig. 117.

Cyclone Separators.

Cyclone separators are used in conjunction with, or as integral parts of, pulverising mills.

Summary of Advantages and Disadvantages of Methods of Conveying Pulverised Fuel.

General Information regarding Methods of Fuel Distribution; no consideration being given to plant used for the Pulverising of the Fuel.

Features of conveying systems.	Screw conveyor method.	Blowing tank system.	Coal-dust and air mixture systems. (See Note A.)	Pumping system.
Discharge from pulveriser mill to storage bunker or direct to furnaces.	Usually into bucket elevator, or screw conveyor when several mills are installed, or by air separation from mill direct into storage bunker, or on to screw conveyor for supply to furnaces.	Usually into bucket elevator as for screw conveyor system for storage of fuel in bunker over blowing tank, or by air separation from mill to storage bunker.	Usually into bucket elevator as for screw conveyor system for storage in bunker above fuel feeders to the mixing fans, or by air separation from mill to storage bunker.	Sometimes direct into pump at each mill for direct supply to furnace bins, or by means of pump- or bucket-elevator into storage bunker above the supply pumps, or by air separation from mill to storage bunker.
Distribution.	Slow-running screw conveyors erected on trestle construction. Difficult to arrange in congested works and to provide supply in various directions. Costly, cumbersome and unsightly, though very reliable if not overloaded.	From the blowing tank pulverised fuel conveyed through 3 or 4 in. pipe with normal bends and branches. Pipe line overhead or underground in convenient position out of sight. Moisture or freezing to be guarded against.	From the mixing fans through large diameter tapering trunk mains sometimes 2 and 3 ft. in dia. run throughout the works. All joints must be air-tight. Costly, cumbersome, and supply irregular when demand is intermittent.	Direct from the mills or the storage bunker. Fuel fed into pumps and conveyed through pipes as for blowing tank system. Moisture and freezing not so likely to interrupt supply as in the blowing tank system.
Danger of reabsorption of moisture in humid climates.	Screw conveyors may have to be run say half full of coal in contact with water-laden air, thus imparting moisture to the fuel, but if run full reabsorption of moisture is not material.	Fuel is forced through standard steel pipes so that absorption of moisture is not excessive providing that condensed water in pipes is drained away.	Pulverised fuel all the time in direct contact with the water-laden air, a perfect method of imparting moisture to minute coal particles.	Fuel in contact with a smaller percentage of air than for any other system.
Wear and tear.	Very slight internal wear. Trestle structure, casings and covers exposed to weather require periodical repainting and conveyor casings must be maintained weather tight.	Very slight running wear. Maintenance no more than for water or gas pipes.	Wear of ducts due to friction usually heavy, more so at bends, which must be reinforced. No sign is given when pipes are wearing thin before actual break through occurs. Mixing fan blades wear away quickly unless made of special steel or strongly reinforced.	Pipe maintenance as for blowing tank system. Pump spindles are cut away where fuel passes over same to the pump outlets.
Fuel storage.	In small bulk at the boilers or furnaces *where it is wanted.*	In small bulk at the boilers or furnaces *where it is wanted.*	In one or two large bins at the mill-house *where it is not wanted* and at considerable distance from boilers or furnaces.	In small bulk at the boilers or furnaces *where it is wanted.*
Supply.	From bins at the boilers, etc., thus ensuring supply over any normal period of mill or conveyor breakdown. Each furnace or boiler is an independent unit having	As for screw conveyor.	By means of high-speed initial mixing fans, and supplementary booster fans along the supply route. Stoppage of any one of these fans places the whole supply system out	As for screw conveyors.

... sumption for say 5 or 6 tons per hour conveyed 1000 ft. 20 hour day.	800 to 1000 h.p. hrs. (20 hours operation.)	600 to 700 h.p. hrs.	3000 to 3500 h.p. hrs.	800 to 1000 h.p. hrs.
Approximate total h.p. of motors.	40 to 45 h.p. (See Note B.)	80 to 100 h.p. (See Note B.)	200 to 220 h.p. (See Note C.)	40 to 50 h.p. (See Note D.)
Feeder motors.	For boilers or furnaces, say, 0·5 to 1·0 h.p. per feeder, positive supply.	As for screw conveyors.	None required.	As for screw conveyors.
Fuel regulation.	Positive regulation by variable or constant speed feeder motors.	As for screw conveyors.	Regulation by mixture supply valve. Furnace or boiler demand may be irregular and burners starved, especially at end of trunk main or near booster fans.	As for screw conveyors.
Flame control and heat regulation.	By varying the speed of feed screw, or the opening through the adjustable jaws of constant speed feeders. Air control by usual shutter valve.	As for screw conveyors.	By opening or closing branch valve fixed close up to the main supply pipe. Adjustment of valve has tendeney to bank up coal-dust behind the valve, thus causing "puffing."	As for screw conveyors.
CO_2 in products of combustion.	With coal feeders set, and air supply regulated accordingly, CO_2 in waste gas remains uniform for uniform furnace condition.	As for screw conveyors.	Variation in coal-dust mixture due to variation in temperature and humidity of atmosphere, to the building up of dust in the supply pipes, and to the varying demand on the main supply, the relation of coal-dust to air in mixture may vary, and CO_2 in waste gases become irregular.	As for screw conveyors.
Explosion and spontaneous combustion.	Spontaneous combustion in the fuel supply bins, if it takes place, results in a slow smouldering in the bin. The hot coal which cakes in the centre of the mass can be run through the screw feeders into the burners and so dealt with. The bulk storage is not at the mill-house, but is held in smaller bulk at the furnaces.	As for screw conveyors.	Spontaneous combustion taking place in the bulk storage at the mill building may be a difficult matter to deal with. The smouldering coal cannot be mixed with air and distributed through the supply pipe. Under normal conditions of running, if the fan pressure drops or ceases, there is a danger of back-fire into the supply pipe, producing an explosion which may flash back to the mill building and cause considerable damage.	As for screw conveyors.

NOTE A.—This summary applies to bulk distribution from the mill house. Local distribution by this system has been advocated in this Chapter under certain circumstances.
NOTE B.—Includes motors for elevator at pulveriser mill and for screw feeders at burners. No power for air supply included.
NOTE C.—Includes motors for air separator at pulveriser mill, initial mixing fans and two booster fans. No power for half the air supply included.
NOTE D.—Includes motors for pump taking delivery direct from pulveriser mill and for screw feeders at burners. No power for air supply included.
If elevator used at pulveriser mill total power somewhat reduced.

The arrangement of a cyclone separator, as installed in conjunction with a Raymond Pulverising Mill, is shown in Fig. 81.

An air separator is also used at the return end of a loop supply main for the collection of the surplus fuel in the Holbeck or similar air and coal-dust mixture system of supply.

A cyclone separator installed as a receiver for pulverised fuel at the end of a pipe line, as in the Quigley and other air pressure transportation systems, is shown

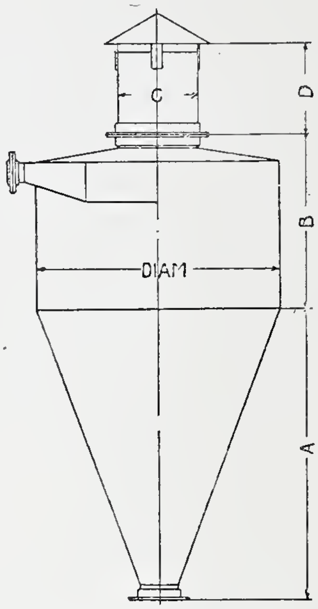


Fig. 115.—Quigley Pulverised Fuel Cyclone Separator for Furnace Supply Bins.

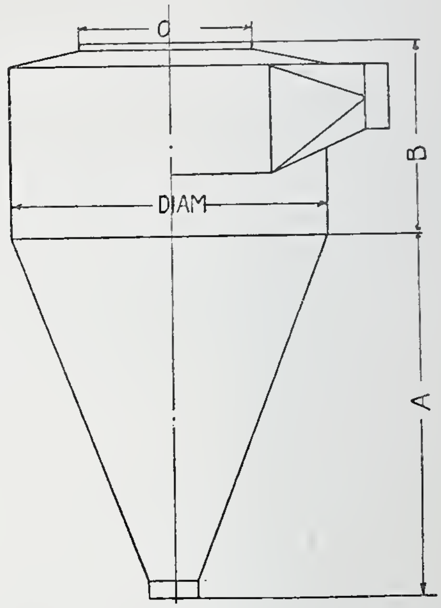


Fig. 116.—Quigley Pulverised Fuel Cyclone Separator for Coal Dryers.

Diam. Cyclone.	Inlet pipe diam.	Discharge pipe diam.	A.	B.	C.	D.	Weight, lb.
36″	3″	6″	3′4″	28¾″	15″	To suit conditions.	300
50″	4″	8″	5′2½″	38⅜″	18″		450
60″	6″	10″	6′2″	42¾″	22″		700
84″	6″	12″	8′7¼″	50¾″	28″		1200

Diam. Cyclone.	Inlet pipe diam.	Discharge pipe diam.	A.	B.	C.	Weight, lb.
3′6″	10″	10″	3′10″	2′4″	2′0″	220
4′6″	12″	10″	4′10″	2′11½″	2′6″	360
5′6″	14″	12″	51′0″	3′5″	3′0″	550
6′6″	16½″	12″	7′4″	4′0″	3′6″	930
7′6″	19½″	14″	8′6″	4′6″	4′0″	1240
8′6″	22″	15″	9′6″	5′0″	4′6″	1600
9′6″	25″	18″	10′6″	5′6″	5′0″	2000

in Fig. 118; this is necessary for releasing the air and for filtering it from the flue coal-dust.

The Fuller-Kinyon Pumping System does not necessitate the use of any cyclone separators; the air which is released from the fuel in the supply bin gradually escapes from the bin by way of the vent pipe.

In the Grindle System of conveying fuel by low-pressure compressed air, separators are necessary, and the special types designed for this purpose are shown in Figs. 119 and 120.

Fig. 119 indicates the rectangular type used when head room is limited. A

Fig. 117.—Quigley Fuel Bin Indicator.

The Quigley Fuel Systems, Inc.]

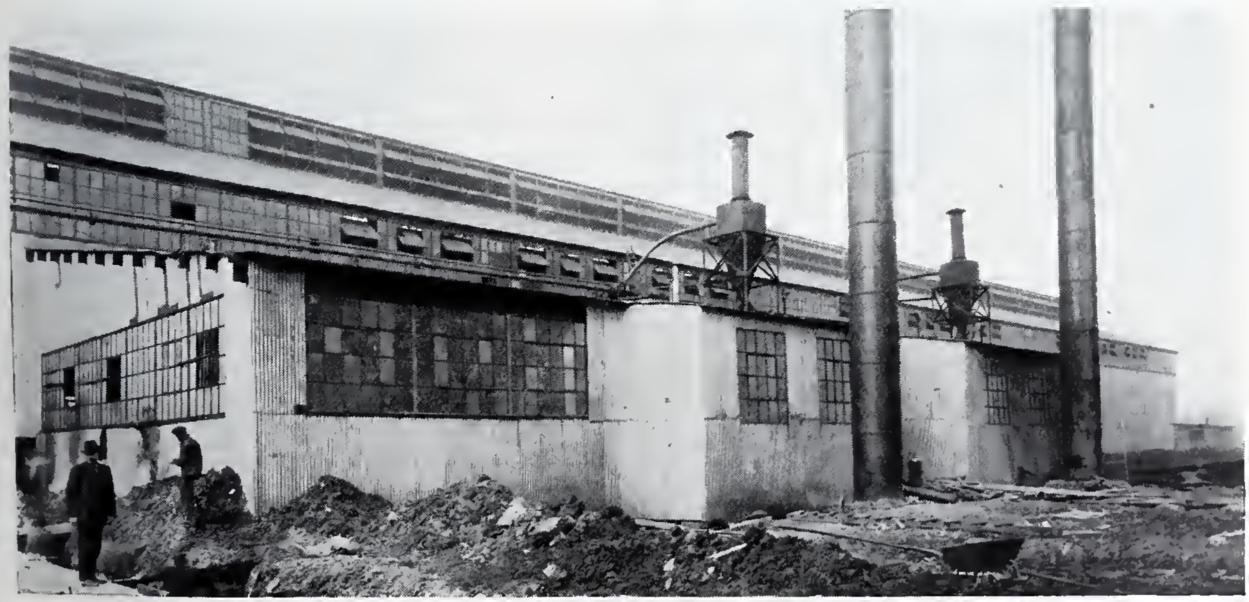


Fig. 118.—Quigley Cyclone Separators, Fuel Transportation Pipes and Switch Valves.

Quigley Fuel Systems, Inc.]

[*To face p.* 230.

Fig. 119.—Grindle Rectangular Air Separator for Furnace Fuel Supply Bins.

The Grindle Fuel Equipment Co.]

Fig. 120.—Grindle Circular Air Separator for Furnace Fuel Supply Bins.

The Grindle Fuel Equipment Co.]

vent connection from the hopper is made at the left, the air being filtered through the cloth tubes, and the coal-dust which collects in the bottom portion can be removed periodically. Where head room permits the circular filter, Fig. 120, is used. This is placed on the top of a fuel bin; the fine dust and air enter the filter tubes, the filtered air escaping to the atmosphere, and the coal-dust falls back into the bin.

Dimensions of cyclone separators for the purpose of filtering the air from fuel delivered by compressed-air systems and for use with coal dryers are given in Figs. 115 and 116.

CHAPTER XII

PULVERISED COAL FEEDERS, FEEDER-MIXERS, AND BURNERS

Essential Features of Pulverised Fuel Burners—Variable Speed Screw Feeders—Variable Speed Motors and Mechanical Gears—Constant Speed Screw Feeders—Compressed Air Syphon Feeders—Table Feeders—The Arrowood Burner—The Quigley Burner—The Bergman Burner—The Lopulco Feeder-Mixer—The Covert Burner—The Pruden Carburiser—The Santmeyer Burner—The Grindle Burner—Fuller Burners—Special Burners—Water-Cooled Burners—Burners for Steel Melting Furnaces—Steam Turbo-Blowers

The processes of drying, pulverising, and conveying the fuel to the bins of the furnaces having now been explained, we proceed to discuss briefly the last items completing the whole cycle of operations, viz. the more usual types found in practice of Feeders, Feeder-Mixers, and Burners.

If the fuel has been mixed with air at the mill-house and conveyed in this manner, by means of mixing and booster fans supplying the conveying air current, through the loop mains, nothing further than secondary air supply at the furnaces and simple "pipe" burners is necessary. No screw feeders, no motors for same, either constant or variable speed, and no other speed control devices are required. The fuel mixture in the supply main must be taken "as found." Whether it is rich in fuel or lean, whether the fuel particles are coarse or fine, whether the mixture is regular or "puffy," it must be accepted; no alteration is possible.

On the other hand, for any of the types of burners to which fuel is fed from a supply bin at the furnace, either screw feeders must be used, or the fuel must be syphoned from the container by means of compressed air.

Repeated failures in the early days of burning pulverised coal were in a great measure due to the fruitless attempts to burn the fuel in too confined combustion chambers, thus imparting high velocity to the products of combustion, and depositing partially burned fuel and ash on the boiler tubes, or on the contents of a furnace. This fault was aggravated by the employment of compressed air at high pressures (from 60 to 80, or 100 lb. per sq. in.) for introducing the fuel into the furnaces, and for the supply of most of the air required for combustion.

When the fallacy of high-pressure injection of fuel in this manner was realised, and larger areas were given to combustion chambers, a variety of mechanically operated feeders were patented and used for a time, but all the early and crude types of feeders and burners gave but very imperfect results, and have long since been remodelled or discarded.

As a departure from the high-pressure compressed-air type of burner, early designs of "low-pressure" burners were of the rotary table type, simple screw feeder, and the friction brush or Schwartzkopf feeder. The next departure was the

longer screw flight mounted upon a horizontal spindle and enclosed in a casing to which fuel could be supplied. By these means it became possible to feed the pulverised fuel into the low-pressure blast of air.

Essential Features of Pulverised Fuel Burners.

For the general run of metallurgical furnaces burners of simple design are used. These consist mainly of an air-blast pipe into which the coal dust is fed from the screw feeder. The dust falls into the air stream, and in this way is carried into the combustion chamber.

Certain special burners or mixers have been designed, whereby a premixing of the coal dust and air is effected in one or more stages before the final mixture emerges from the burner nozzle.

With the simple type of burner having the one air-supply pipe, final adjustment of the air for complete combustion can be effected by regulation of the amount of natural draught air induced.

The actual design of a burner must be governed to a great extent by the conditions under which fuel is to be burned, and the type of furnace to be heated. Collins, in his Paper " The Use of Coal in Pulverised Form," American Institute of Mining Engineers, 1918, refers to some of these points and to the general type of burners used :—

" A good mixing projector, or burner, should be so designed that it will receive the pulverised coal in regulated quantities, break up the stream of fuel, and so distribute it that each particle is surrounded by the correct proportion of air. It must also project the fuel into the furnace at the velocity required by the operation, and must be so proportioned as to deliver the necessary volume of air at the proper velocity. Four types of burners are employed :—

" (*a*) Induction type, in which a high-velocity air induces and entrains the necessary additional air, and projects it into the furnace at low velocity; this type has the high-velocity air under control as well as the induced air.

" (*b*) Positive type, in which the high-velocity air induces and entrains the fuel and projects it into a positive, larger column of low-velocity air, thereby breaking up the fuel stream evenly, and disseminating it through the larger column of low-velocity air, before it enters the furnace. The larger column of low-velocity air is usually preheated, in stoves located in a chamber through which the waste gases from the furnace pass; temperatures of preheating range from 100° to 600° F. in the better designed systems of stoves. Both columns of air are positive, being generated by fans or pressure blowers, while gates regulate the quantity.

" (*c*) Single type, in which the high-velocity air first induces and entrains the fuel stream, after which a high pressure jet of air, applied usually in the centre of the stream, gives a sharp projection of flame and quick distribution of the fuel through a larger volume of preheated air at quite low velocity. This type of burner is usually adjustable in direction. The heated air ranges in temperature from 2200° to 1300° F., as in open-hearth practice; usually 10 to 15 % of the air enters

with the fuel, and 85 to 90 % from regenerators. The stack draft through the regenerative chambers is regulated by a valve.

" (*d*) Single type, in which the high-velocity air induces and entrains the fuel and projects it into the furnace, as in rotary kiln practice, under usually 5 to 6 oz. pressure from a fan. The additional air required for combustion is induced by stack draft, and enters around the hood and through the kiln discharge opening.

" Air pressures of $\frac{3}{8}$ oz. entering the combustion chambers of some types of furnaces, from air and fuel mixing burners, up to 2 lb. in pressure jets of other types, have been in successful constant use for years. Stack draft should be of only sufficient intensity to create a partial vacuum in the furnace, thereby helping the fuel and air into and not out of the chamber; its strength must be enough, however, to extract all the products of combustion."

It will be explained later that compressed air is now used only in small quantities as a means of syphoning the pulverised fuel from the container, or in somewhat larger quantities when pulverised coal is used for firing open hearth steel-melting furnaces.

Medium pressure burners—10 to 20 lb. per sq. in. on the air supply—are also practically non-existent to-day; the only application approaching medium pressure is that connected with self-contained pulverising units, in which the pressure on the air supply may be as high as 5 lb. per sq. in.

The successful burning of fuel in any specified furnace area is to so great an extent dependent both upon the rate of initial velocity and the velocity of exit gases, that these factors practically account for success or failure with pulverised fuel firing.

On this subject, W. G. Wilcox has put the facts succinctly in his paper upon " Control of Fuel and Air in Burning Pulverised Coal," Western New York Section of American Chemical Society, as recorded in the *Colliery Guardian*, October 1918, in which he says :—

" The rapidity of combustion and the completeness of combustion of a mixture of coal dust and air depend upon a number of factors; for example, they are dependent upon the velocity and pressure at which it is passed into the combustion chamber. If the velocity of the incoming stream of powdered coal and air is above the velocity of flame propagation, combustion will not take place until the mixture has slowed down to a point that it does not exceed the velocity of flame propagation. When a powdered coal is fired at high pressure and high velocity, combustion frequently does not begin until a point 4 ft. to 6 ft. from the mouth of the burner. A similar example is found in the plumber's blow torch when too much air is used, or in the Bunsen burner when the gas pressure is too high. High-pressure firing not only slows down combustion, but has a destructive action on the furnace. It has been well established that high velocities in the combustion chamber or a blow-torch effect due to firing at high pressure (whether oil or gas be used as a fuel) are always destructive of the brickwork. This action is increased in high-pressure firing of powdered coal, since, in addition to the erosional effect of the gases at high temperature travelling at high velocity, there is a fluxing action by the melted ash. Furthermore, the slagged ash will be carried along mechanically, leading to further furnace

troubles. In one case this resulted in a deposit of slag on the mud drum of a vertical waste heat boiler at the end of a long reverberatory furnace. Slowing the velocity not only hastens combustion, but makes it possible to eliminate much of the slag. When the velocity is low the coalesced particles of slagged ash are either larger than will be carried by the velocity of the gas, or this condition is so nearly approached that a slight change in direction of the flame will result in dropping out the slag. Thus, in addition to being correct combustion and necessary in order to avoid excessive furnace maintenance costs, low velocity combustion, by a slight change in flame direction, permits the dropping out of a large quantity of the slagged ash in the early part of combustion, where it can be removed and will not interfere seriously with efficient metallurgical operations.

" A study of the flame developed at a low pressure by an intimate mixture of coal dust and air shows that combustion is extremely rapid. In a copper reverberatory furnace at Florence, Colorado, where this type of combustion is used, coal burned at the rate of approximately one ton an hour develops a flame that vanishes within 6 ft. of the burner, combustion being complete at that point. Let us translate this into terms of natural gas, in which case the fuel consumption would be approximately 26,000 cu. ft. per hour, or 433 cu. ft. per minute. You can picture to yourself this quantity of gas being burned at low pressure and developing a flame only 6 ft. long. Samples of gas taken in the flame show a content of CO_2 as high as 16 % only 5 ft. from the mouth of the burner. This will give an example of the rapidity with which combustion can be obtained and the possibilities of shortening the flame. With proper equipment it is equally practicable to lengthen the flame until it will spindle out a distance as great as 100 or 120 ft. However, with an intimate mixture under control, this must be done by supplying insufficient air. Under such conditions combustion is incomplete and the flame spindles out because combustion continues to develop throughout the length of the furnace as air leakage supplies additional oxygen. This is proof of the statement that the length of flame is an actual measure of efficiency of mixing and the adjustment of the fuel air ratio."

The more or less crude methods so generally employed for mixing pulverised fuel with the requisite air for combustion certainly do not produce that intimate mingling of fuel and air that should be accomplished, but for all practical purposes these methods are sufficient to ensure good results.

Wilcox and Arrowood are in favour of a more thorough mixing of the fuel and air by means of specially designed apparatus or carburettors. M. W. Arrowood, executive engineer for the Ground Coal Engineering Co., Chicago, has made a special study of pulverised fuel feeding devices, and has scientifically investigated the several factors governing the adequate intermixing of fuel and air in correct proportions and at suitable velocities.

He examined several hundred types of apparatus, and gave the results of his investigations and the conclusions arrived at in a series of articles. He says :—

" Aside from a few freak exceptions, practically all the apparatus developed resolve into one or two classes, which may be broadly designated as pulverised fuel feeders of the 'jet' or 'injector' types. By no possible stretch of the

imagination can it ever be supposed that a ' jet ' stream of coal carrying a small part of the air required for complete combustion, and entering the furnace at a high velocity (in many cases upward of 10,000 ft. a minute) will bring about such conditions that the fine coal particles secured at no little expense for crushing, drying, and grinding, shall perform the legitimate function to be expected, viz. complete and entire combustion with the chemically necessary amount of oxygen.

"It is obvious, of course, that such a high-speed jet, depending on stack draft or other means of introducing a volume of air for combustion, does not give any appreciable mixing effect of the fuel in the air prior to delivery to the furnace."

Arrowood points out the improbability of proper mixing of the fuel with the streams of combustion air when the latter are divided into two supplies at different pressures. It has always appeared to the author of this book that air for combustion of fuel in a furnace should either be supplied at one pressure, or, when a higher pressure is used for the introduction of the fuel, the quantity of air at the higher pressure should be reduced to a minimum volume. The small volume of air at high pressure will then expand and slow down on emerging from the central orifice of the burner, and enable secondary low pressure air to mingle better with the fuel jet. On this question Arrowood says: —

"It seems to be common practice with such apparatus to use a pressure of about 8 ounces in the central blast pipe, and a pressure of perhaps not more than 1 or 2 ounces in the larger pipe in those cases where secondary air is supplied in this pipe rather than leaving it open to the atmosphere. In any event, a comparatively high pressure, and hence relatively high discharge velocity, must be used with any type of feeder that contemplates commingling in the furnace. This is for the reason that the blast must always have enough energy to commingle with the gas currents. Since the mass of the moving stream is light, its velocity must be correspondingly high to supply the kinetic energy required for commingling.

"The velocity of a jet discharging into atmospheric pressure under a maintained pressure of 8 ounces is 14,388 ft. per minute. On the other hand, a similar jet at a maintained pressure of $1\frac{1}{2}$ ounces has a velocity of 6315 ft. per minute. The question immediately arises, ' How long will it take the volume of air travelling at 6000 ft. per minute to catch up with the coal travelling at nearly 15,000 ft. per minute? '

"That some means of checking the tremendous velocity of such blast feeding jets must be adopted is readily seen. Even in a comparatively large furnace, say 50 ft. long, the coal, if allowed to proceed at the initial velocity of, say, 15,000 ft. a minute, would remain in the furnace less than one-fifth of a second.

"Uniform diffusion of one gas into another is one of the most difficult of laboratory experiments. Many published accounts of investigations along these lines indicate the extreme tendency of gases to stratify. Bulletin No. 135 of the Bureau of Mines is filled with such references. If gas mixing is difficult, it seems illogical to employ a process which increases the volume of gases that must be diffused through each other to get efficiency.

" Any effective means of control must lie in apparatus properly designed for the purpose of performing the primary objects of commingling and mixing of the fuel and air outside the furnace.

" Assuming the fuel and gases to be moving at a given velocity, the more quickly combustion takes place, the more time will be available for the gases to impart heat to the work in hand. Hence every effort should be made to complete combustion as rapidly as possible. The finer the coal is ground, the more quickly it can be burned, so that the limit of fineness desirable in a given plant is determined at the point of diminishing return on costs for grinding.

" Another factor indicating the importance of rapid combustion is the use of preheated air. Extensive combustion experiments on the combustion of gas and fuel oil with preheated air have indicated that the total saving in the furnace is ordinarily from three to four times as great as the actual heat recovered in preheating the air. This can only be due to the quicker combustion and earlier liberation of heat which make possible a more efficient imparting of the heat produced to the work in hand.

" This is not only an argument for preheating the air with pulverised coal or any other fuel, but also demonstrates the necessity of thoroughly understanding the time factor in combustion and heat application, and the effect upon it of thoroughly mixing the fuel and air.

" The time element is a matter of the greatest importance in boiler applications and similar work, where it is necessary that the combustion be completed close to the point where fuel enters the furnace, in order to avoid impinging partly burned material on the tubes, thereby reducing materially the efficiency of the equipment."

Variable Speed Screw Feeders.

To effect variable feed of fuel, the speed of the screw flight spindles had to be regulated, and in a great many feeders of present-day design this is the principle still employed, improvement in detail only differentiating these from the designs of many years ago.

The actual screw flight of a feeder should be relatively long and should fit closely into the bore of its cast-iron housing ; if the screw is too short or fits too loosely in the housing, there will be danger of dry pulverised fuel flushing right through, either when the screw is in motion or stationary. Iron slide gates should be provided to cut off the supply from the fuel bunker to the screw feeder.

Fig. 121 shows a standard type of screw feeder, the rated capacities of which are given below :

3 in.	dia.	screw	feeder	300	lb. per	hour	at 30 r.p.m.
4 in.	,,	,,	,,	650	,,	,,	,,
5 in.	,,	,,	,,	1300	,,	,,	,,
6 in.	,,	,,	,,	2000	,,	,,	,,

and other ratings in direct proportion to the speed of rotation.

Feeders of the screw-feed type will not operate at all if certain qualities of coal contain moisture in excess of 10 %, and, generally speaking, feeders can only be relied upon to function satisfactorily when moisture does not exceed 5 % to 6 %. Pulverised lignite and peat, however, being exceptionally light, can be satisfactorily passed through feeders when there is 15 % or so of moisture in the fuel.

The rated feeder capacities given herein for supply of pulverised coal must be halved in order to arrive at the capacity of a feeder for lignite or peat fuel, for, owing to the light nature of lignite and peat, feeders for same must be run at double the listed speeds of ordinary coal feeders to obtain equal rate of fuel supply.

To facilitate the taking down of a screw feeder, should this become blocked, the feeder body should preferably be of the split type. This enables the lower portion of a feeder to be removed, and the central spindle and screw flight removed or cleared of packed fuel.

Fuller screw feeders, shown in Fig. 123, are of this design. The quantities of pulverised coal that can be passed through these at 100 r.p.m. can be based on the following table :

2 in. dia. (over screw flight)	90/100	lb. coal per hr.
3 in. ,, ,, ,, ,,	270/300	,, ,, ,,
4 in. ,, ,, ,, ,,	620/650	,, ,, ,,
5 in. ,, ,, ,, ,,	900/1000	,, ,, ,,
6 in. ,, ,, ,, ,,	1500/1600	,, ,, ,,

The amount of pulverised coal delivered by a Fuller screw feeder at other speeds will vary somewhat with the nature of the fuel and the moisture contained therein, but will be approximately proportional to the r.p.m. of the screw flight.

The Grindle variable speed screw feeder is illustrated in Fig. 124. In this form it is so made that several feeders can be conveniently bolted together and attached to the bottom of a supply bin.

Capacities of Grindle Feeders.

Size.	Capacity per Minute (lb.).		Capacity per Hour (lb.).	
	Minimum.	Maximum.	Minimum.	Maximum.
M 4	½	2	30	120
M 5	1	3	60	180
M 6	2	6	120	360
M 7	4	12	240	720
M 8	8	24	480	1440
M 9	12	36	720	2160
M 10	24	72	1440	4320
M 11	36	108	2160	6480

The Covert screw feeder is shown in Fig. 125.

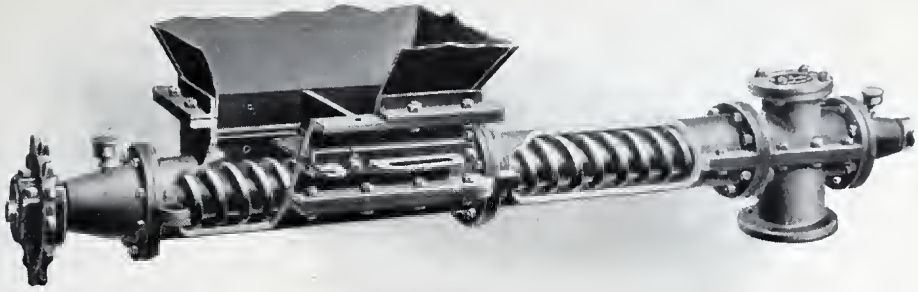


FIG. 121.—STANDARD VARIABLE SPEED FULLER SCREW FEEDER.

The Fuller Engineering Co.] *[The Fuller Lehigh Co.*

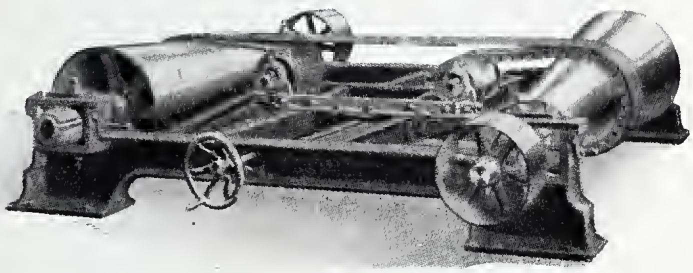


FIG. 122.—MOORE AND WHITE VARIABLE SPEED GEAR.

The Moore and White Co.]

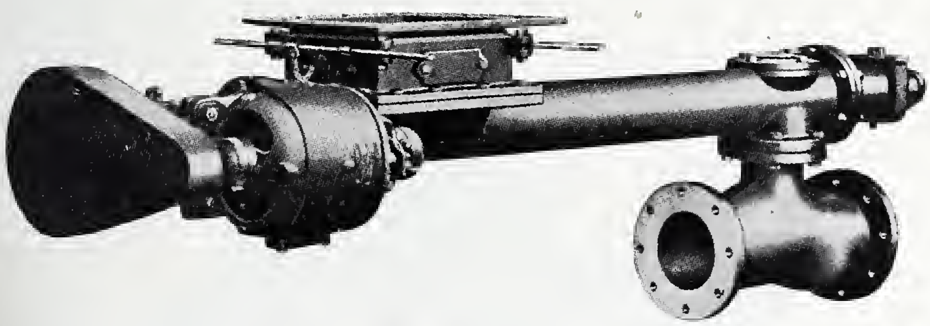


FIG. 123.—FULLER SCREW-FEEDER, SHOWING VARIABLE SPEED MOTOR AND ENCLOSED GEARING.

The Fuller Engineering Co.] *[The Fuller Lehigh Co.*

[To face p. 238.

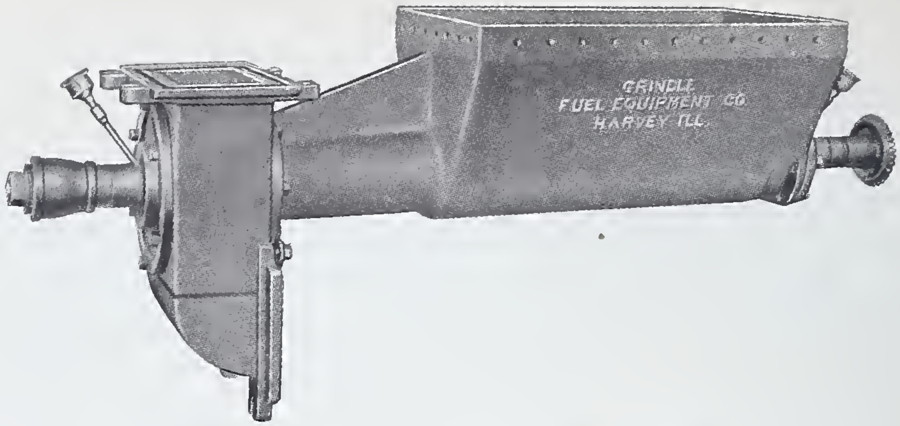


Fig. 124.—Grindle Variable Speed Screw Feeder, arranged for Assembly in Multiple Units.

The Grindle Fuel Equipment Co.]

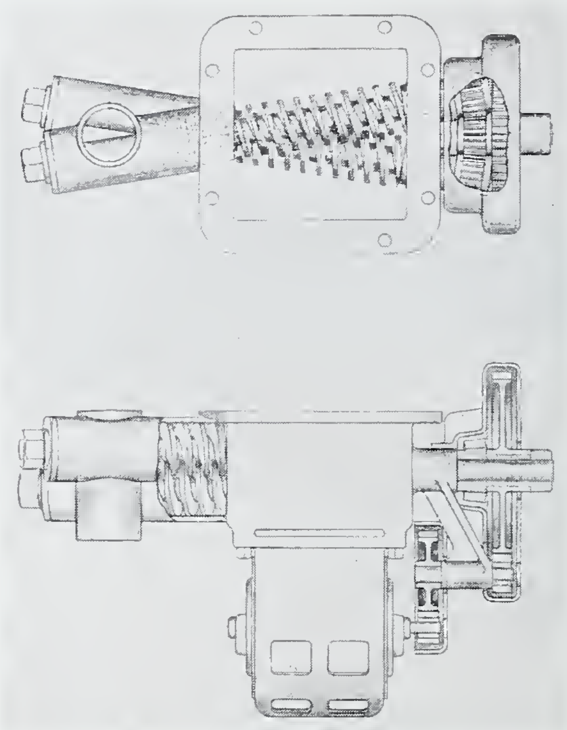


Fig. 125.—Covert Screw Feeder, showing Variable Speed Motor and Gearing.

Heyl and Patterson, Inc.]

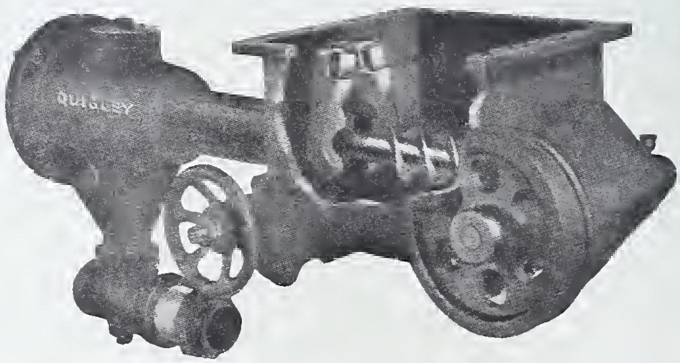


Fig. 126.—Quigley Constant Speed Feeder, showing Adjustable Jaws for Control of Fuel Supply.

Quigley Fuel Systems, Inc.]

Variable Speed Motors and Mechanical Gears.

Variable speed continuous-current electric motors (usually 1 h.p.) are employed for varying the speed at which screw feeders of the type illustrated above must be run in order to regulate the rate of fuel supply. This necessitates the provision of a motor generator at the mill-house, or subsidiary motor generators in the various departments of a works, when alternating current only is available. Variable speed alternating current motors have not proved very successful.

Should electric current not be available, and the variable speed fuel feeders be run off line shafting, some other means must be provided for obtaining the range and gradation of speed variation necessary for successful fuel firing. This can be accomplished by installing a mechanical variable speed apparatus of the sliding belt and coned pulley type. A view of a Moore and White variable speed change equipment, driven by a constant speed alternating current motor, is shown in Fig. 122. The belt to the pulley on the fuel feeder shaft would pass round the pulley shown at the top of the illustration. Change in speed is effected by moving the link belt across the surfaces of the two cone speed-reduction pulleys.

Another type of variable speed control apparatus of a novel description is referred to in *Power*, December 27, 1921. This apparatus is supplied by the Oilgear Co. of Milwaukee, Wis., and consists essentially of an oil pump which can be adjusted through a wide range of delivery. The working fluid, oil, is contained in the apparatus, the pump delivering the oil to a motor whieh controls the secondary speed required. The apparatus is actuated by constant-speed lineshaft or motor, and transmits the power received at any required speed of the secondary shaft, from zero to a maximum, in either direction, and at an efficiency at full load of 85 %.

The amount of oil handled by each cylinder at each revolution depends on the stroke. If the operator sets the stroke at zero, no oil will be pumped. If the pump is at maximum, a large steady flow of oil is drawn in. Any speed selected by the operator will be maintained irrespective of changes in load, unless the load becomes excessive, when an automatic overload gear comes into operation.

It is claimed that this system lends itself readily to various positions of remote and pilot control, so that it may be found suitable for driving coal conveyors, mixers, and feeders, and even for coal pulverisers and stokers.

Constant Speed Screw Feeders.

To eliminate the variable speed drive, Culliney invented the double screw feeder, whereby the excess of fuel not required at the burner could be returned by means of the second screw to the inlet end of the feeder. This apparatus met with a certain measure of success, but "choking" frequently occurred in the fuel returned, particularly so when the pulverised coal was a little damp.

An outcome of this type of feeder is the constant-speed adjustable jaw feeder designed and supplied by the Quigley Co., and shown in Fig. 126.

This is the only constant-speed fuel feeder known to the author, all other designs met with in practice being of the variable speed type. A good range of control

can be obtained with this type of feeder, with dry coal. A feeder rated at 500 lb. per hour will operate at regular feed down to 25 lb. per hour.

Compressed Air Syphon Feeders.

Opinion whether mechanically operated screw feeders should be used, or the compressed-air syphon type of feeder, appears to be very much divided.

The use of screw feeders, as briefly described in the following pages, usually necessitates the provision of small variable or constant-speed motors. The complete equipment for a large number of feeders is, in consequence, somewhat expensive, but the collective power required for operating them is considerably less than that absorbed by syphon feeders. To take an example, the delivery of 500 lb. of coal per hour by means of screw feeders would absorb approximately 1·85 h.p. The power that would be used for supply of compressed air for syphon feeder delivering fuel at this rate would be about 3·06 h.p.

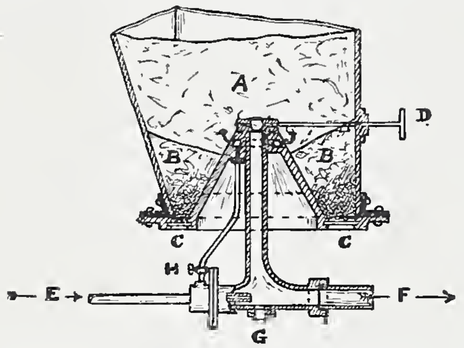


Fig. 127.—Suggested Arrangement of Syphon Feeder for Dry Fuel Supply.

A dry pulverised coal. *B* wet fuel. *C* slides or drains to remove water, etc. *D* fuel supply control valve. *E* compressed air supply. *F* fuel feed to furnace burner. *G* plug for access to fuel valve *D*. *H* air supply cock for aerating ring *J*. *J* aerating ring to prevent backing.

It is claimed, however, for the syphon system that there need be no stoppage of fuel feed owing to wet coal caused by condensation of moisture collecting at the bottom of a supply bin. When this occurs, and screw feeders are used, it may be that the motors will fail to move the screw flights and the motors will stall.

The syphon method of fuel feed enables the suction pipe to be so arranged that " dry " fuel some distance above the actual bottom of the fuel supply bin can be extracted, thus leaving the lower fuel, which may have become saturated with condensed moisture, in the bunker. Under certain conditions this may be an advantage, but for normal work it would seem better practice to remove slightly damp fuel as soon as possible, thus preventing the collection of water that may in time reduce the pulverised coal to a " slurry."

The syphon type of feeder is simple and relatively inexpensive; the main cost of the equipment is naturally the air compressor (and standby machine) and the run of air piping.

An approved arrangement of syphon feeder is shown in Fig. 127.

Several large installations, which at the outset were equipped with screw feeders and motors, have since been remodelled, and syphon feeders adopted, notably at some of the largest steel works in America.

For the operation of syphon feeders, 20 cu. ft. of free air per min. compressed to 60 lb. per sq. in. are required per burner for puddling or reheating furnaces consuming fuel at the rate of 500 lb. per hour; or $8\frac{1}{3}$ lb. of fuel per burner per min. The quantity of air used at this pressure is therefore about 2·4 cu. ft. of free air per lb. of coal per min. The quantity of free air to be compressed for the supply of 500 lb. of fuel per hour will therefore be 1200 cu. ft.

It will be found that, in compressing 1 cu. ft. of free air per min. at sea level to 60 lb. per sq. in., 0·13 h.p. will be theoretically absorbed; and for 20 cu. ft. per min., 2·6 h.p. The power for compressing 1200 cu. ft. free air per hour will then be, theoretically, 2·6 h.p.; and, allowing 85 % efficiency for the compressor, the total power absorbed will be 3·06 h.p. (or 3·06 h.p. applied during the period of 1 hour of fuel supply).

For the burning of pulverised fuel, it is necessary to supply approximately 150 cu. ft. of air per lb. of coal. Say that, of this quantity, 20 % is to be supplied at high pressure. Therefore for the burning of $8\frac{1}{3}$ lb. of fuel per min., 1250 cu. ft. of air will be required—250 cu. ft. to be compressed to 60 lb. per sq. in., and the balance of 1000 cu. ft. to be supplied as secondary air at low pressure, say, 6 oz. per sq. in.

It will be found that the theoretical power absorbed in the supply of air at 6 oz. per sq. in. is 0·0017 h.p. per cu. ft. Thus for 1000 cu. ft. the theoretical power taken will be 1·7 h.p. or 1·7 h.p. hours for the 500 lb. of coal.

Assume the efficiency of a rotary fan to be 50 %, the power for low-pressure air supply then becomes 3·4 h.p. Overall total power is thus $3{\cdot}06 + 3{\cdot}4 = 6{\cdot}46$ h.p.

For the operation of a screw feeder for supplying fuel at the rate of 500 lb. per hour to a low-pressure burner, it is found that about 1 h.p. will be absorbed by the motor, or 1 h.p. hour for 500 lb. of coal.

The quantity of air at low pressure, 6 oz. per sq. in. for $8\frac{1}{3}$ lb. of coal per min. will be $8\frac{1}{3} \times 150 = 1250$ cu. ft. of air per min., and the theoretical power absorption for this duty will be $0{\cdot}0017 \times 1250 = 2{\cdot}12$ h.p. Again, assuming 50 % efficiency for the rotary fan, the power used then becomes 3·18 h.p. or 3·18 h.p. hours for 500 lb. of coal.

Overall total power is thus 1 h.p. hour + 3·18 h.p. = 4·18 h.p.

The saving in power by the use of a screw feeder and full quantity of air at low pressure will thus be 2·28 h.p. or a saving of say 35 % in the actual power applied. On the other hand, it will be found that it is convenient and often cheaper to use syphon feeders, which have no moving parts and cost about one-tenth that of screw controllers; furthermore, they are safe, require no attention, no grease, belts, etc.

Table Feeders.

Many of the original controllers for feeding pulverised fuel into the air supply for combustion in furnaces were of the "table" or "brush" design. The latter, notably the Schwartzkoff (see Preface), was found unreliable for even distribution of fuel, but of present-day "table" feeders a reliable design is offered by the Simon-Carves Company, and is illustrated in Fig. 129.

This consists of a disc having therein a number of holes and revolving between two plates; the upper plate has ports communicating with the fuel supply in the bin, while the lower plate is provided with discharge outlets through which the fuel is delivered to the burner. The holes, or receptacles, in the rotating disc become filled with pulverised fuel, which is delivered in the quantity required, through a regulating device, to the supply pipe. The fuel not required remains in the holes in the revolving disc, and is carried past the delivery ports, returning under the feed

plate. It will thus be seen that only the holes which have been cleared can be refilled with pulverised fuel. It is claimed that good results and accurate control are obtained with this type of feeder.

The Arrowood Burner.

The outcome of Arrowood's prolonged study of combustion conditions, as these affect the thorough mingling of pulverised fuel with the air supply, has been the design of a special burner shown in Fig. 128. This apparatus has been standardised in various sizes from the large industrial type of burner down to the small fuel feeder necessary for rivet heating or similar furnaces.

It is made on the Arrowood principles, of incorporating the best methods of

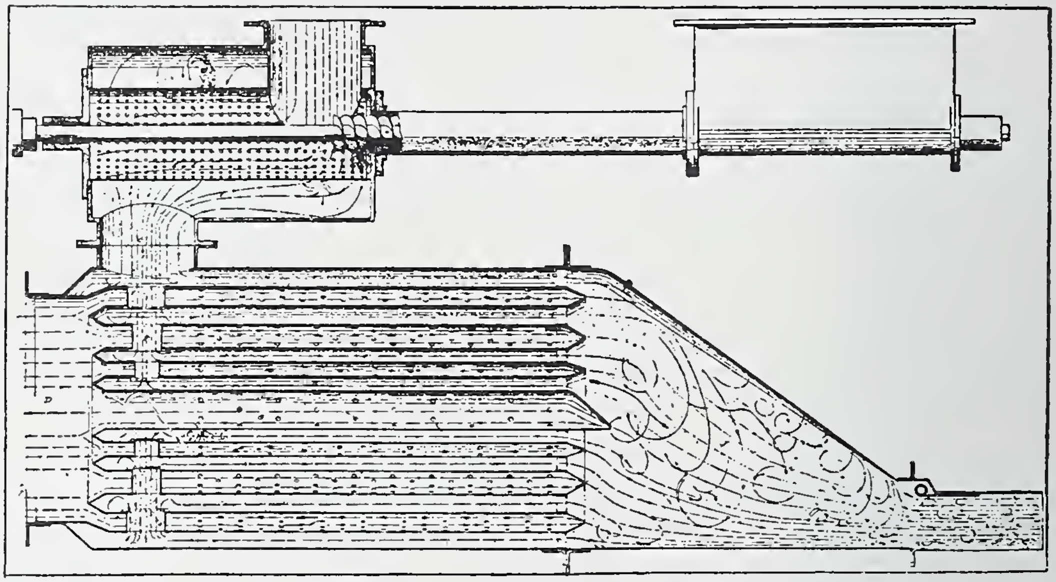


Fig. 128.—Diagram of Arrowood Pulverised Fuel Burner.

(*John Blizard.*) (*Department of Mines, Canada.*)

rapidly and intensively mixing large or small quantities of pulverised fuel with a minimum of air for combustion, by thorough separation of the coal particles, and the diffusion of the bulk of fuel through the much larger volume of air. In this apparatus a screw feeder is used to introduce the pulverised fuel into the primary mixing chamber, the air entering at A, mixing with the fuel, and both passing through the perforated cylinder B into the next of the parallel distributor tubes, between which the balance of air for combustion passes from the inlet E to the burner outlet, where both streams meet at the same velocity.

Two illustrations of Arrowood burners are shown in Figs. 130 and 131, the former depicting burners applied to annealing ovens at the Ohio Brass Company's works, and the latter the burner equipment for the brass-melting furnaces at the same works.

The Quigley Burner.

Fig. 132 illustrates one of the Quigley burners as fitted to the combustion

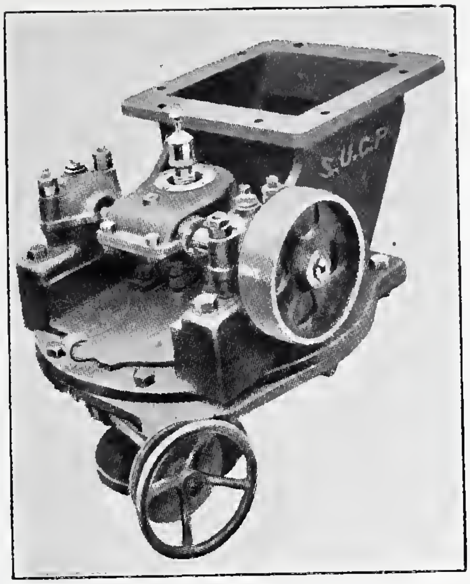


FIG. 129.—SIMON-CARVES TABLE FEEDER.

Simon-Carves, Ltd.]

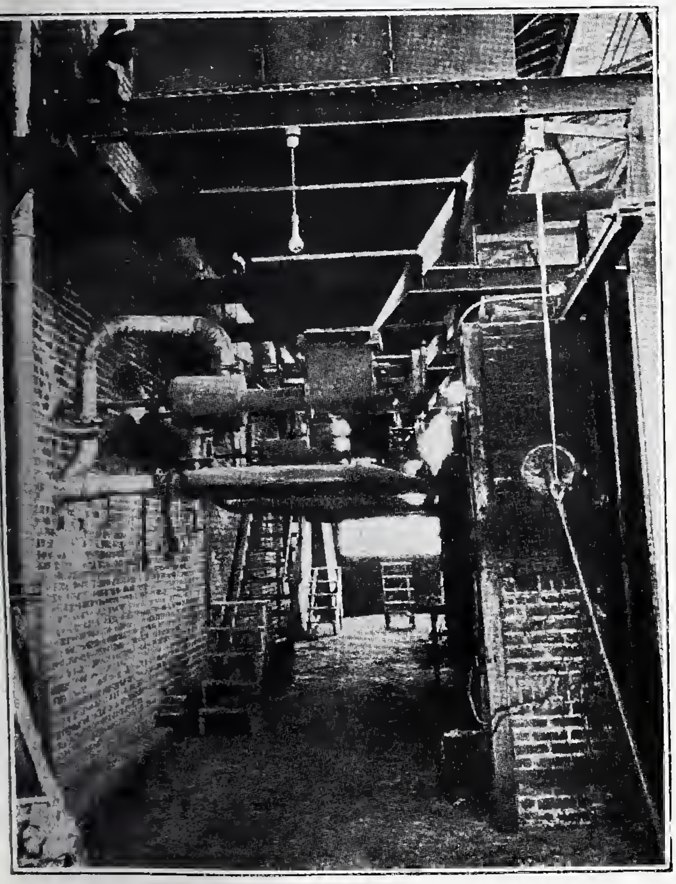


FIG. 130.—ARROWOOD MIXER-BURNERS, AS APPLIED TO ANNEALING OVENS FOR MALLEABLE IRON AT OHIO BRASS CO.'S WORKS.

Combustion, July 1922.] [*Ground Coal Engineering Co.*

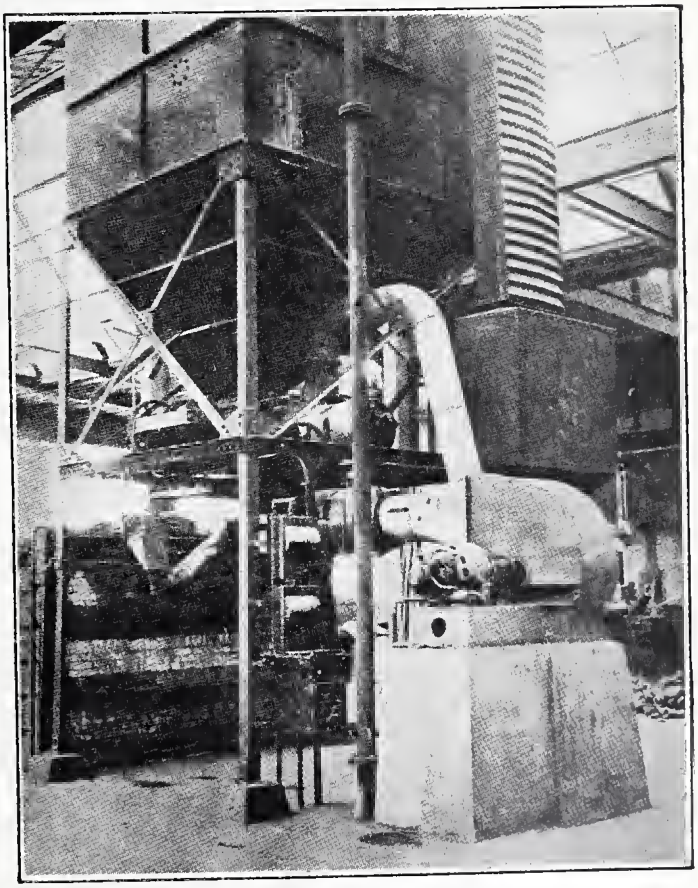


FIG. 131.—ARROWOOD MIXER-BURNERS ON MELTING FURNACE AT OHIO BRASS CO.'S WORKS.

Combustion, July 1922.] [*Ground Coal Engineering Co.*

[*To face p.* 242.

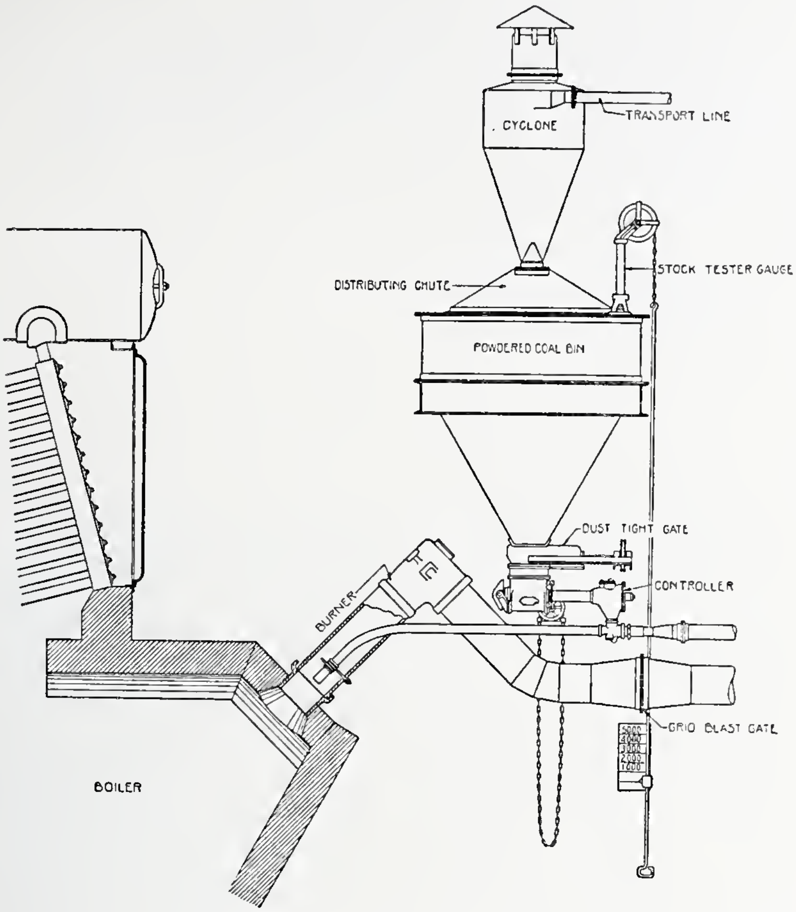


Fig. 132.—Quigley Pulverised Fuel Burner as applied to Water Tube Boiler.
(*The Hardinge Co.*) (*Quigley System.*)

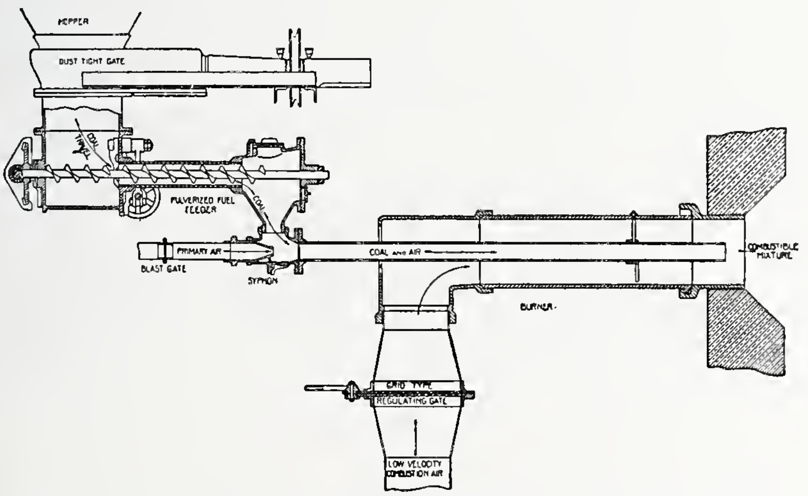


Fig. 133 —Quigley Central Duct Type of Burner for Primary (high) and Secondary (low velocity) Air Supplies.

chamber of a boiler; the course of the pulverised fuel from the hopper, through the screw feeder to the primary air and fuel supply pipe, can be clearly followed. Secondary air for combustion of the fuel is supplied through the larger pipe directly connected up to the rear end of the burner.

In addition to the conclusions arrived at by Arrowood against the use of two sources of air supply at different pressures, the extra power required, and the added cost of duplicate fan and air supply pipe equipment are further considerations in favour of air being supplied at one pressure only, although the air pipes can be duplicated at the burner when it is required to split up the currents.

The standard "Quigley" burner as shown in Fig. 133 is constructed to operate with a double air supply, but provided from the one source and therefore of equal pressure. The primary air has an ejector action upon the supply of powdered coal. The initial mixture of coal dust and air is then introduced into the main air supply just prior to its entry into the furnace. The pressure of the air supply at the point of entry of the fuel is about 2 to 3 oz.

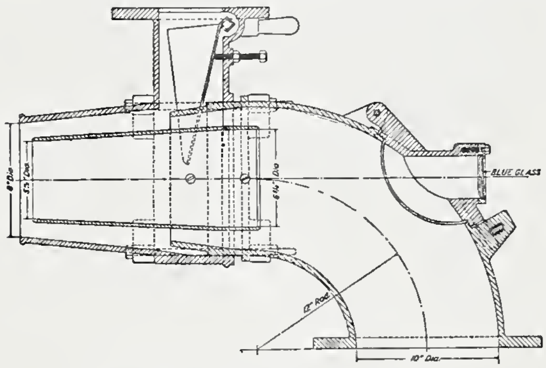


Fig. 134.—Bergman Burner.

The Bergman Burner.

The "Bergman" type of burner, Fig. 134, has an internal cone, fitted concentrically within the air-supply pipe, and the coal dust is fed in by gravity in such a manner that it forms a complete film or coating to the air jet. The purpose of this is to introduce the air into the furnace in the centre of a covering of fuel. It is contended that when coal dust is fed into the centre of the air jet, the latter expands away from the pulverised fuel, and an imperfect mixing of the air and fuel in the furnace results.

The Lopulco Feeder-Mixer.

The Locomotive Pulverised Fuel Co.'s burner mixer, Figs. 135 and 136, as used at the Milwaukee Power Station, is a combination of burner, mixer, and screw feeder. This burner mixer is one of the most efficient types of burners in general use. In practice, air is supplied at 6 to 8 oz. pressure, and enters the jacket surrounding the delivery end of the screw feed. At this point the mixed coal and air is given a whirling motion by means of the paddle blades, which thus assists the intimate mixing of the fuel and air for combustion. From this combination feeder-mixer a number of burner tubes can be supplied.

The Covert Burner.

The Heyl and Patterson Co. ("Covert" system) have several types of burners or mixers. One of these is of special interest. The coal dust falls into this burner in the usual manner by gravity, and on to diaphragm shelves projecting one below the other, and fitted horizontally across the air inlet pipe or burner tube. Air is supplied at 2 or 3 oz. pressure, and picks up the coal dust on passing between the shelves.

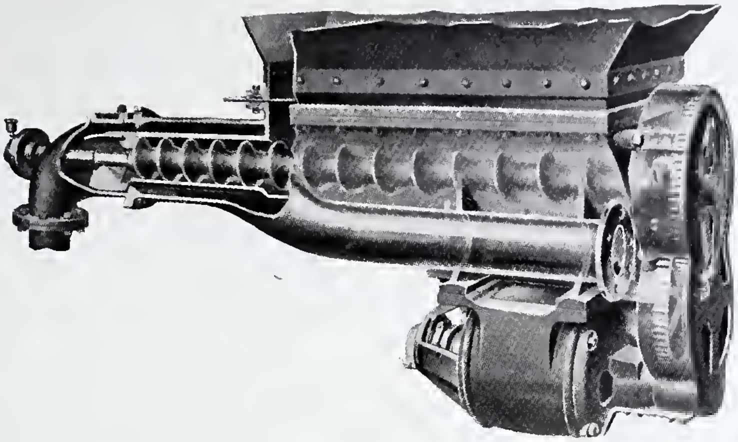


FIG. 135.—LOPULCO FEEDER MIXER.

International Combustion Engineering Corpn.]

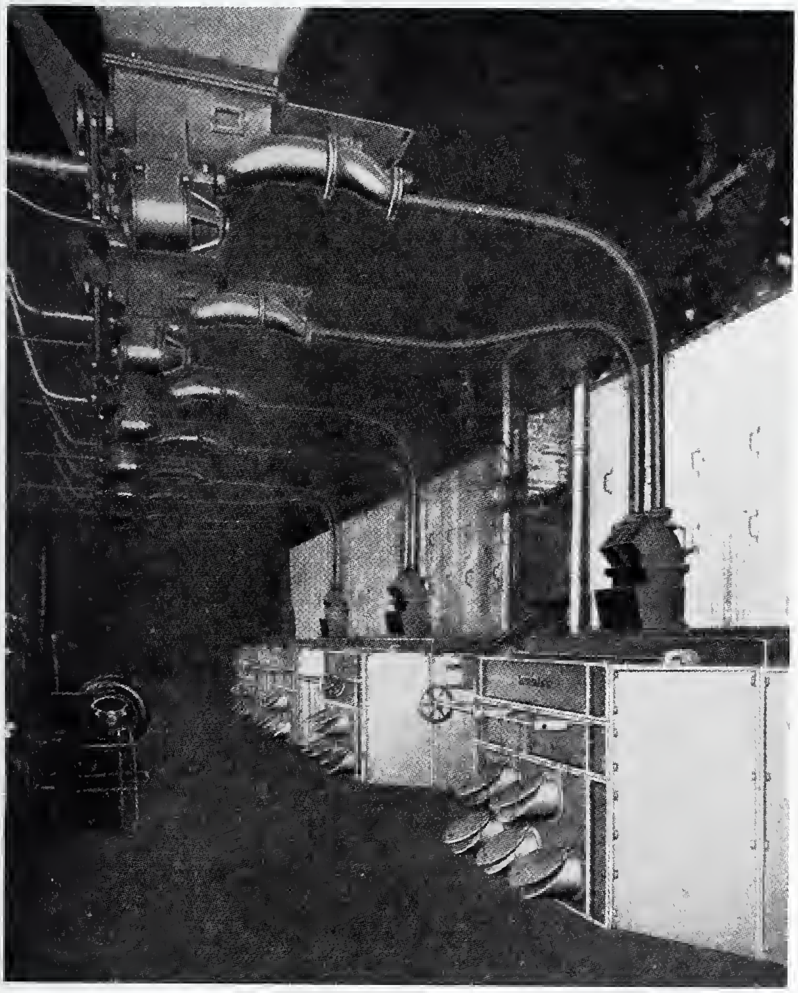


FIG. 136.—LOPULCO FEEDER MIXERS AND VERTICAL BURNERS, AS ARRANGED FOR CENTRAL STATION BOILER FIRING.

International Combustion Engineering Corpn.] [*To face p.* 244.

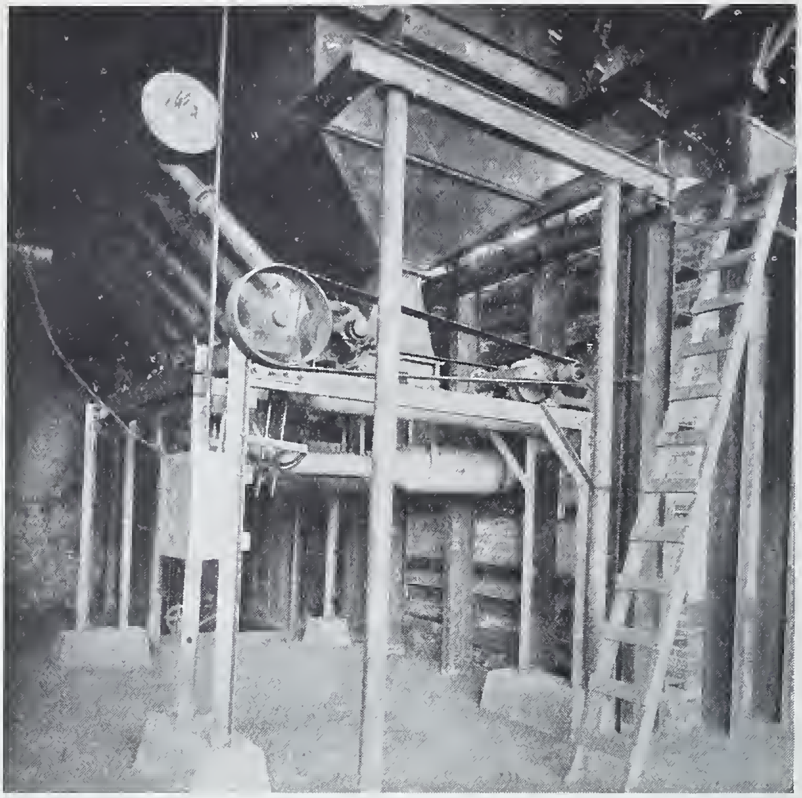


Fig. 137.—Pruden Mixer Burners as applied to Copper-smelting Reverberatory Furnace, showing Reeves Variable Speed Gearing.

The Powdered Coal Engineering & Equipment Co.]

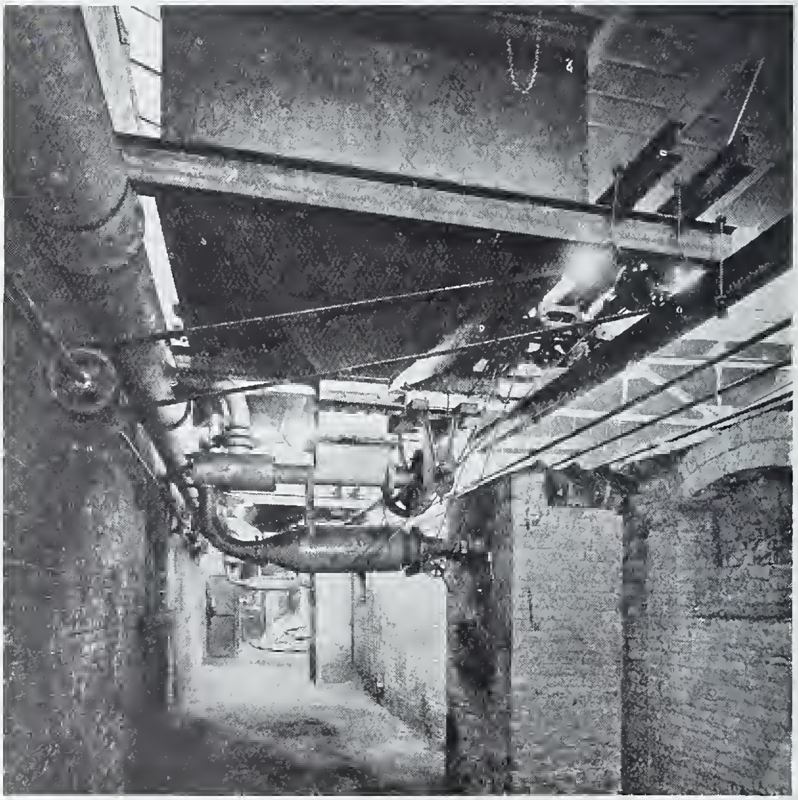


Fig. 138.—Pruden Mixer Burners as applied to Annealing Furnaces.

The Powdered Coal Engineering & Equipment Co.]

The Pruden Carburiser.

For the "Pruden" Carburiser or Mixer, Fig. 137, supplied by the Powdered Coal Equipment and Engineering Co., the powdered coal, as it is withdrawn by screw feeder from the bunker, is mixed with a primary supply of air, and this mixture is then conveyed to a second chamber in which the balance of air required for combustion is introduced into the primary mixture. As applied to annealing furnaces this apparatus is shown in the illustration, Fig. 138.

The Santmeyer Burner.

The "Santmeyer" burner is shown in Fig. 139. The operation of this burner can be clearly seen by reference to the illustration. It has been introduced here

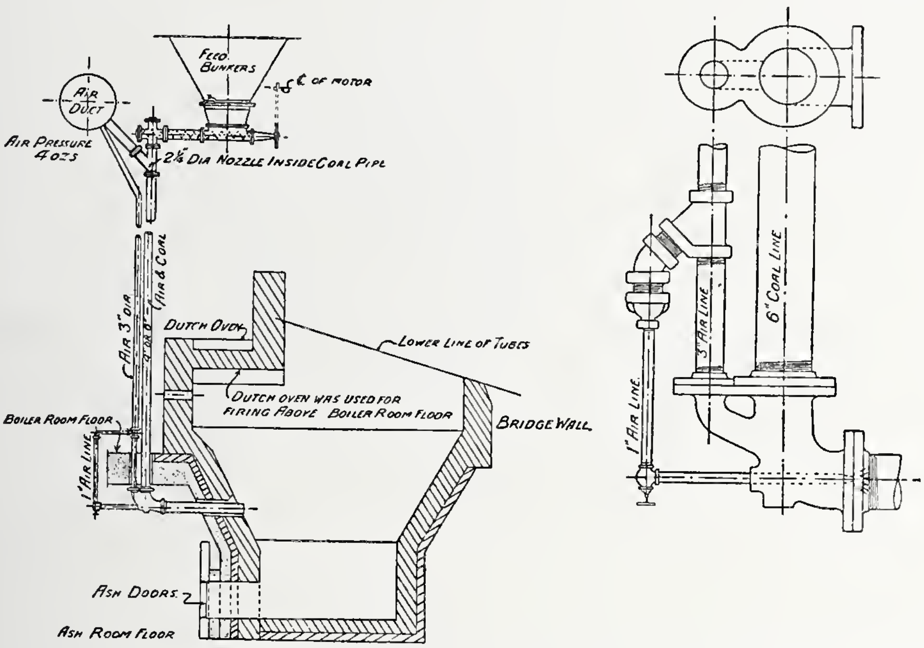


Fig. 139.—Arrangement of Santmeyer Burner and Boiler Combustion Chamber. (*The Puget Sound Traction Light and Power Company, Seattle, U.S.A.*)

because Mr. Santmeyer was the first engineer to burn pulverised fuel successfully on the west coast of America. Burners of this design were fitted to the boiler furnaces at the Puget Sound Electric Light and Power Station, Seattle, when the pulverised coal plant was put into operation in 1917, and are, it is believed, still being used.

The Grindle Burner.

The Grindle burner is shown in Fig. 140. The mixing vanes, which impart a swirling motion to the fuel and air, are incorporated in a separate fitting shown in the inset, Fig 141.

A complete table of capacities for Grindle (Carburettor) burners is given in the table overleaf, in which not only the rate of fuel burning per minute but the volume of air required and nozzle velocities are also recorded.

This table gives a most comprehensive range of burner capacities for pressure on the air supply ranging from $\frac{1}{8}$ oz. per sq. in. to 10 oz. per sq. in., and constitutes a very valuable record of burner data.

Pressure in oz. per sq. inch.	Burner No.	0000	000	00	0	1	1½	2	2½	3	3½	4	4½	5	5½	6	6½	7	7½	8	8½	9	9½	10
	Inlet Dia.	1½	2	2	3	3	4	4	5	5	6	6	7	7	8	8	9	9	10	10	11	11	12	12
⅛ oz.	Lb. coal per min.	·14	·25	·25	·56	·56	1·0	1·0	1·55	1·55	2·24	2·24	3·06	3·06	4·0	4·0	5·03	5·03	6·22	6·22	7·56	7·56	8·96	8·96
	Cu. ft. air per min.	22	40	40	90	90	159	159	249	249	359	359	488	488	637	637	807	807	997	997	1209	1209	1435	1435
	Vel. @ noz. ft. per sec.	15	30	14	30	13	22	12	19	14	20	15	21	15	20	15	18	15	19	15	19	15	18	15
½ oz.	Lb. coal per min.	·28	·5	·5	1·12	1·12	1·98	1·98	3·11	3·11	4·47	4·47	6·1	6·1	7·97	7·97	10·01	10·01	12·50	12·5	15·05	15·05	17·9	17·9
	Cu. ft. air per min.	45	80	80	179	179	319	319	498	498	717	717	976	976	1275	1275	1614	1614	1993	1993	2411	2411	2869	2869
	Vel. @ noz. ft. per sec.	31	61	27	61	25	44	24	38	27	39	31	42	31	39	31	37	31	38	31	37	31	36	31
1 oz.	Lb. coal per min.	·39	·71	·71	1·58	1·58	2·81	2·81	4·4	4·4	6·3	6·3	8·64	8·64	11·22	11·22	14·22	14·22	17·58	17·58	21·3	21·3	25·3	25·3
	Cu. ft. air per min.	63	113	113	253	253	450	450	705	705	1013	1013	1380	1380	1798	1798	2280	2280	2816	2816	3407	3407	4055	4055
	Vel. @ noz. ft. per sec.	43	86	39	86	35	63	36	53	39	55	43	59	43	55	43	52	43	53	43	52	43	51	43
2 oz.	Lb. coal per min.	·56	1·0	1·0	2·23	2·23	3·96	3·96	6·2	6·2	8·93	8·93	12·2	12·2	15·92	15·92	20·0	20·0	24·8	24·8	30·0	30·0	35·6	35·6
	Cu. ft. air per min.	89	159	159	357	357	635	635	993	993	1430	1430	1947	1947	2513	2543	3218	3218	3973	3973	4808	4808	5722	5722
	Vel. @ noz. ft. per sec.	61	121	54	121	50	89	48	75	54	78	61	83	61	78	61	73	61	75	61	73	61	72	61
3 oz.	Lb. coal per min.	·68	1·21	1·21	2·73	2·73	4·85	4·85	7·58	7·58	10·9	10·9	14·85	14·85	19·4	19·4	24·6	24·6	30·4	30·4	36·6	36·6	43·6	43·6
	Cu. ft. air per min.	109	194	194	437	437	777	777	1214	1214	1748	1748	2379	2379	3107	3107	3933	3933	4857	4857	5876	5876	6993	6993
	Vel. @ noz. ft. per sec.	74	148	66	148	61	108	59	92	67	96	74	101	74	96	74	90	74	91	74	89	74	88	74
4 oz.	Lb. coal per min.	·78	1·4	1·4	3·14	3·14	5·58	5·58	8·75	8·75	12·6	12·6	17·1	17·1	22·4	22·4	28·3	28·3	35·0	35·0	42·2	42·2	50·2	50·2
	Cu. ft. air per min.	126	224	224	503	503	895	895	1398	1398	2014	2014	2741	2741	3580	3580	4532	4532	5595	5595	6770	6770	8057	8057
	Vel. @ noz. ft. per sec.	86	171	76	171	70	124	68	105	76	110	86	116	86	110	86	104	86	106	86	104	86	102	86
5 oz.	Lb. coal per min.	·88	1·56	1·56	3·51	3·51	6·23	6·23	9·75	9·75	14·0	14·0	19·1	19·1	25·0	25·0	31·6	31·6	39·0	39·0	47·2	47·2	56·2	26·2
	Cu. ft. air per min.	140	250	250	561	561	998	998	1560	1560	2247	2247	3058	3058	3995	3995	5056	5056	6242	6242	7553	7553	8989	8989
	Vel. @ noz. ft. per sec.	96	191	85	191	78	139	75	118	85	112	96	132	96	123	96	115	96	118	96	116	96	113	96
6 oz.	Lb. coal per min.	·96	1·71	1·71	3·84	3·84	6·82	6·82	10·7	10·7	15·3	15·3	20·9	20·9	27·2	27·2	34·6	34·6	42·7	42·7	51·5	51·5	61·5	61·5
	Cu. ft. air per min.	153	273	273	613	613	1091	1091	1706	1706	2456	2456	3344	3341	4367	4367	5527	5527	6824	6824	8257	8257	9827	9827
	Vel. @ noz. ft. per sec.	105	209	93	209	85	152	82	128	94	133	105	143	103	135	105	132	105	129	105	126	105	124	105
7 oz.	Lb. coal per min.	1·0	1·84	1·84	4·13	4·13	7·35	7·35	11·5	11·5	16·5	16·5	22·6	22·6	29·5	29·5	37·3	37·3	46·0	46·0	55·7	55·7	66·2	66·2
	Cu. ft. air per min.	165	294	294	661	661	1176	1176	1839	1839	2648	2648	3604	3604	4707	4707	5958	5958	7356	7356	8900	8900	10592	10592
	Vel. @ noz. ft. per sec.	113	225	100	225	92	163	89	139	101	145	113	154	113	145	113	142	113	139	113	136	113	133	113
8 oz.	Lb. coal per min.	1·1	1·96	1·96	4·41	4·41	7·85	7·85	12·3	12·3	17·7	17·7	24·0	24·0	31·4	31·4	39·6	39·6	49·0	49·0	59·2	59·2	70·7	70·7
	Cu. ft. air per min.	176	314	341	705	705	1255	1255	1961	1961	2825	2825	3845	3845	5022	5022	6356	6356	7848	7848	9495	9495	11301	11301
	Vel. @ noz. ft. per sec.	120	240	107	240	98	175	95	148	107	155	120	164	120	155	120	152	120	148	120	145	120	143	120
9 oz.	Lb. coal per min.	1·46	2·08	2·08	4·66	4·66	8·26	8·26	12·9	12·9	18·7	18·7	25·4	25·4	33·3	33·3	42·0	42·0	51·8	51·8	65·5	65·5	74·6	74·6
	Cu. ft. air per min.	186	332	332	746	746	1328	1328	2076	2076	2989	2989	4070	4070	5315	5315	6727	6727	8306	8306	10050	10050	11961	11961
	Vel. @ noz. ft. per sec.	127	254	114	254	104	185	100	157	113	163	127	174	127	163	127	161	127	157	127	153	127	151	127
10 oz.	Lb. coal per min.	1·2	2·19	2·19	4·9	4·9	8·75	8·75	13·7	13·7	19·7	19·7	26·7	26·7	35·0	35·0	44·2	44·2	54·5	54·5	66·0	66·0	78·6	78·6
	Cu. ft. air per min.	196	350	350	785	785	1397	1397	2184	2184	3145	3145	4281	4281	5591	5591	7076	7076	8728	8728	10572	10572	12582	12582
	Vel. @ noz. ft. per sec.	134	267	119	267	109	194	105	165	119	172	134	183	134	172	134	169	134	165	134	161	134	158	134

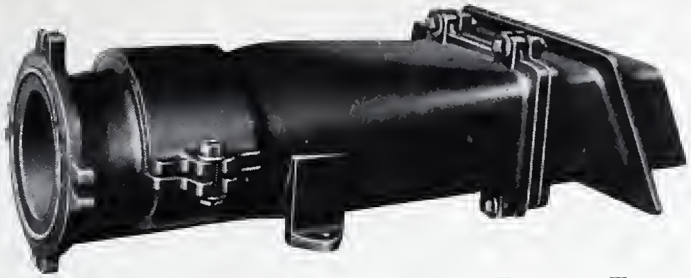


Fig. 140.—Grindle Burner with Flange Type Angle Nozzle for Oblique Firing.

The Grindle Fuel Equipment Co.]

Fig. 141.—Mixing Vane Attachment of Grindle Burner.

The Grindle Fuel Equipment Co.]

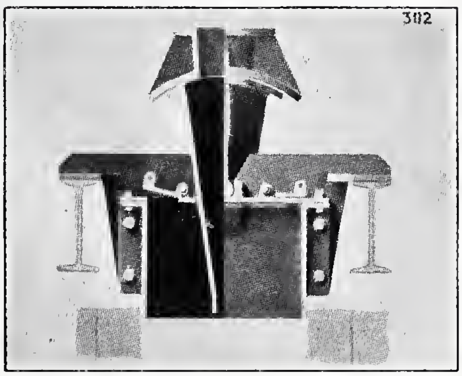


Fig. 142.—Fuller Vertical Flare Type Burner.

The Fuller Engineering Co.]
[*The Fuller Lehigh Co.*

[*To face p.* 246.

Fuller Burners.

The usual sizes of pulverised coal burners for the more general requirements in metallurgical and boiler applications, such as the Fuller induction single-air supply burners, Fig. 143, are rated for the following maximum quantity of fuel per minute :—

$4\frac{1}{2}$ in.	burner rated for	15 lb. fuel per minute.
$6\frac{1}{4}$ in.	,, ,, ,,	25 ,, ,, ,,
$7\frac{1}{4}$ in.	,, ,, ,,	30 ,, ,, ,,
8 in.	,, ,, ,,	35 ,, ,, ,,

For short discharge burner pipes, *i. e.*, when the mixing of the fuel with the air for combustion is effected within a few feet of the burner orifice, the size of pipes for low-pressure air supply, and the size of the actual burner pipes for the rate of fuel

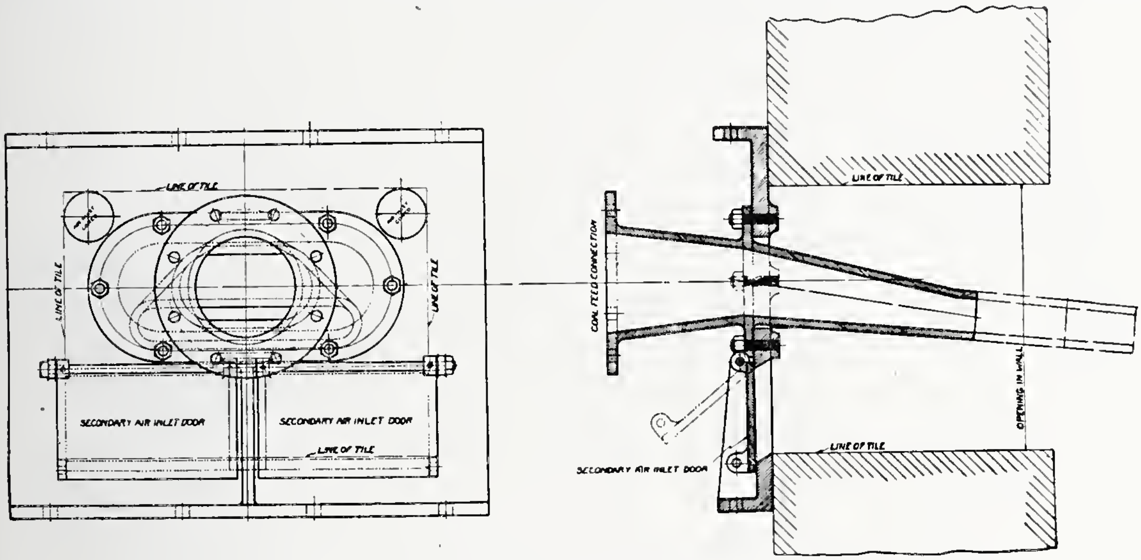


FIG. 143.—Front Elevation and Section of Fuller Horizontal Type Burner.
(*The Fuller Engineering Co.*). (*The Fuller Lehigh Company.*)

supply stated as for the Fuller burners illustrated in Fig. 143, are recorded below.

It is assumed in each case that 150 cu. ft. of air at a pressure of about 5 in. water gauge or 3 oz. per sq. in. is allowed per lb. of pulverised coal burnt.

Correct velocity and intimate mixing will occur under these conditions.

Rate of fuel feed per minute.	Air supply pipe and burner dia.
1 lb.	$1\frac{1}{4}$ in.
10 ,,	4 ,,
15 ,,	5 ,,
20 ,,	$5\frac{1}{2}$,,
30 ,,	7 ,,
50 ,,	9 ,,
100 ,,	13 ,,
150 ,,	18 ,,

Fuller vertical flare type burners are shown in Fig. 142.

Special Burners.

For heavy duty, or for particular purposes, burners of special shape or character may be required and the burners for the Milwaukee Lakeside Power House boilers, which had to be specially designed to cope with the heavy duty and to ensure the complete burning of the fuel in the very large combustion chambers, are shown in Fig. 144.

Each burner consists of a flattened or fantail nozzle, having a width at its delivery end of 16 in. and an internal thickness of $\frac{5}{8}$ in. The coal-laden stream of air under pressure enters at the top and is delivered to the furnace in a thin sheet. A slight vacuum, from 0·05 to 0·20 in. of water, is maintained in the furnace, so that air is drawn in at the main air inlet at the right, and 20 to 25 % of the full amount of air required enters at this point.

Whether steam boilers or metallurgical furnaces are concerned, the whole question

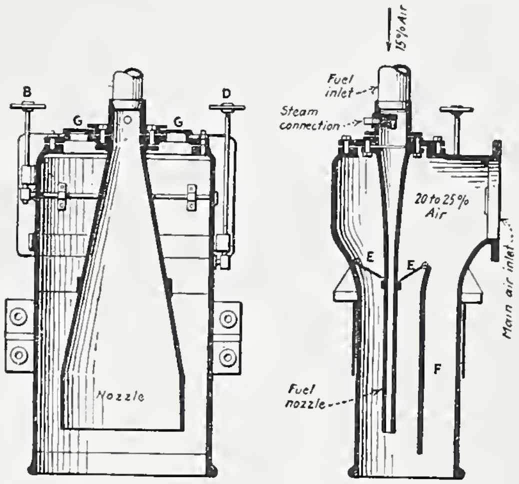


Fig. 144.—Arrangement of Lopulco Burners as used at Milwaukee Lakeside Generating Station. (*Power*, December 19, 1922.)

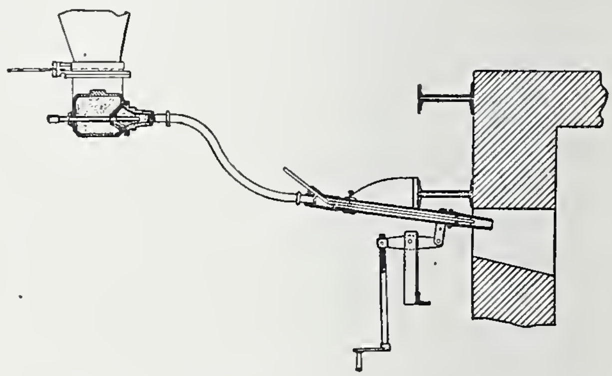


Fig. 145.—Compressed Air Syphon Pulverised Fuel Feeder and Swivel Type Burner as used on Steel-melting Furnaces.

of success or failure may depend upon the manner in which pulverised fuel is introduced into a combustion chamber and upon the design of the latter.

In connection with steel melting furnaces, to quote an example, it is recommended by Barnhurst that the distance from burner orifice to the point of flame cf contact with a bath of metal or edge of the bath should be not greater than 16 to 18 ft., that velocities of gases in the furnace should be low, and that 40 to 60 cu. ft. regenerative volume per ton of steel melted is sufficient for good results. In arranging for the feeding in of the pulverised fuel, 20 to 25 % of the air required for combustion in the form of compressed air enters with the fuel; the balance is supplied at low pressure by rotary fan.

Water-cooled Burners.

It is sometimes found that burners used with the air mixture fuel-conveying system, such as the Holbeck or Bonnot systems, are fitted with end cover plates

permitting of inspection of the flame, and the removal of the slag which may adhere to the burner outlet by raking back the slag through the burner. For high-temperature work, these burners are water cooled, which would appear to be a disadvantage, as it involves the addition of a complicated network of water pipes and a wastage of water.

Why water-cooling should be adopted with this system is not readily explainable, unless it is that, on account of the more perfect mixing of the coal dust with the air supply before the fuel enters the furnace, combustion takes place closer to the burner orifice than with other systems. Coal dust is, however, frequently mixed with the air supply some feet away from the orifice of a burner pipe in other systems, and no water-cooling of the burners has been found necessary.

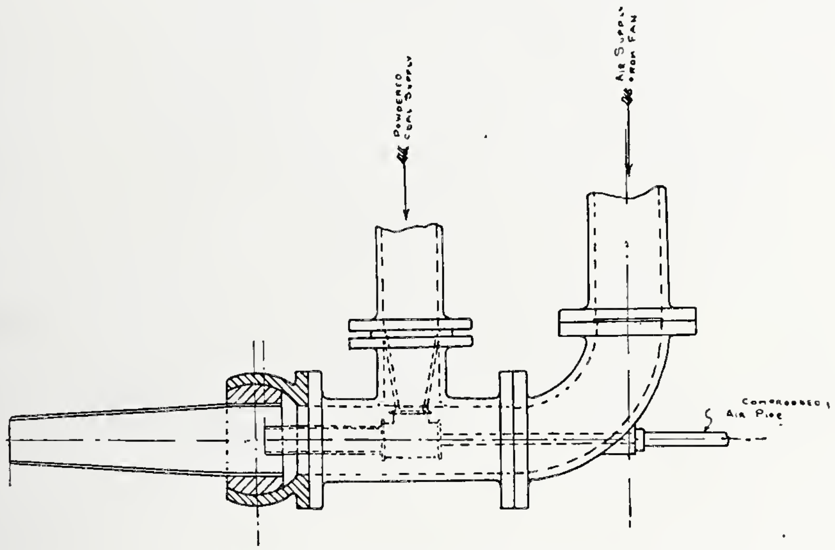


Fig. 146.—Low Pressure Air Supply Pulverised Fuel Swivel Type Burner, as used on Steel-melting Furnaces.

Burners for Steel-melting Furnaces.

When pulverised coal is applied to open-hearth steel-melting furnaces it is desirable to project the flame on to the centre of the bath, in such manner that at each reversal one of the ends may receive the greater proportion of the heat. Burners for this purpose are therefore operated with high-pressure air alone, or with a combination of high- and low-pressure air, the burners being fitted with swivel joint nozzles, so that the flame can be projected in the direction required.

The usual type of burner for high- and low-pressure air is shown in Fig. 145, and, by means of the screw-adjusting gear, the burner nozzle section can be moved in order to control the direction of the flame. A small quantity of compressed air is used to carry the mixture of air and coal dust well forward into the furnace.

The illustration, Fig. 146, shows a burner that has been used in the past for high-temperature work. This is supplied with compressed air only, the coal dust in this case being syphoned out of the fuel bunker. This type of burner is giving place to the high- and low-pressure air burner with which it is an easier matter to use preheated air. It has been maintained that the use of a relatively small

quantity of high-pressure air for open-hearth steel furnaces enables the full flame temperature to be developed in close proximity to the metal, and avoids the overheating of the refractory walls. In either case, it is usual to arrange the burner nozzle a few inches in front of a natural draught inlet port. To prevent overheating of the burners at each reversal, the burner not in use is withdrawn and an iron slide lowered over the inlet port.

In certain instances the reversal of firing is automatically performed, the starting and stopping of the air and coal-dust supplies being operated by electrically controlled gear working in synchronism with the reversal of the chequer valves.

Steam Turbo-Blowers.

Air-supply fans of standard types are used under ordinary circumstances, but, for the supply of the air for combustion of pulverised fuel in isolated cases, it is often convenient and sufficient to connect up a rotary steam blower of the open propeller blade type. Such a unit is shown in Fig. 147, which illustrates the "Wing" Blower. A centrifugal type of "Wing" Turbo-Blower is shown in Fig. 148.

A steam turbo-blower of the "Carling" type is shown in Fig. 150, and a unit suitable for use in connection with the firing of locomotives with pulverised fuel is shown in Fig. 151. This type may sometimes be convenient for use in connection with isolated furnaces where a steam supply is available, as in the case illustrated in Fig. 149, which depicts the pulverised fuel fired boiler equipment at the British Columbia Sugar Co., Vancouver, B.C.

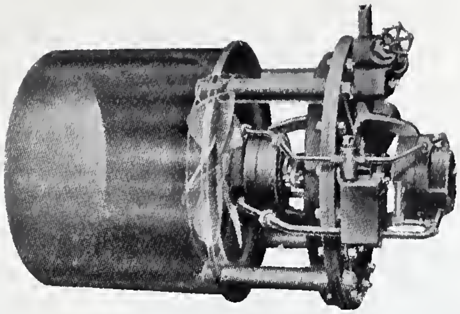


Fig. 147.—Wing Propeller Type Turbo Blower.
L. J. Wing Mfg. Co.]

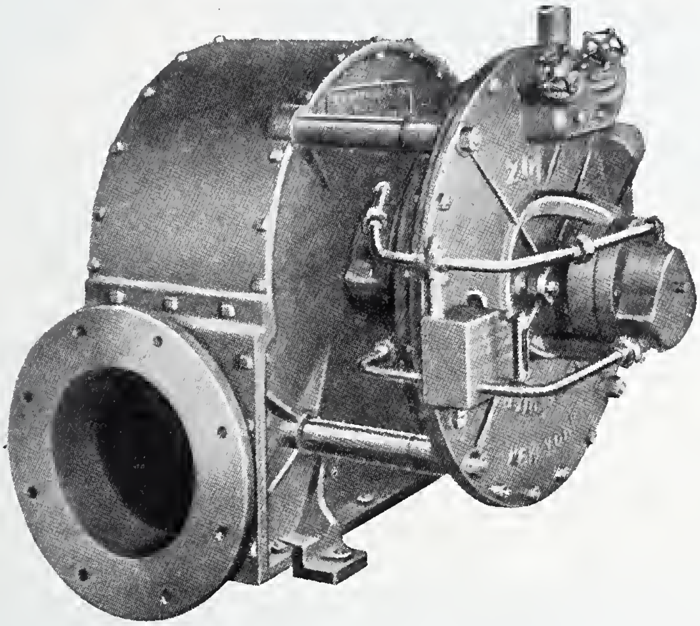


Fig. 148.—Wing Centrifugal Steam Turbo Blower
L. J. Wing Mfg. Co.]

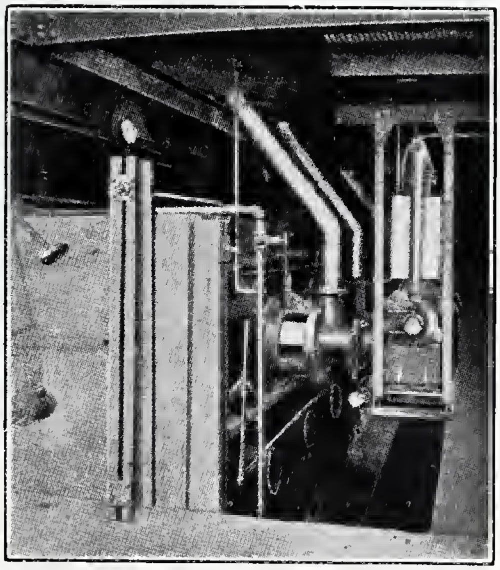


Fig. 149.—Wing Turbo Blowers used in Conjunction with Pulverised Coal Firing at the Works of the British Columbia Sugar Co.
Fuller System.]

[*To face p.* 250.

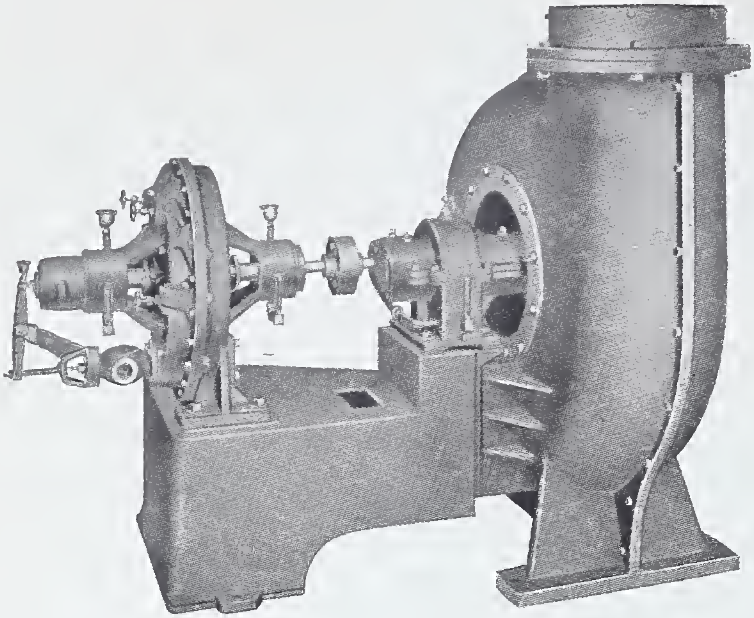


FIG. 150.—CARLING EXHAUSTER FAN DRIVEN THROUGH REDUCTION GEARING.

The Carling Turbo Blower Co.]

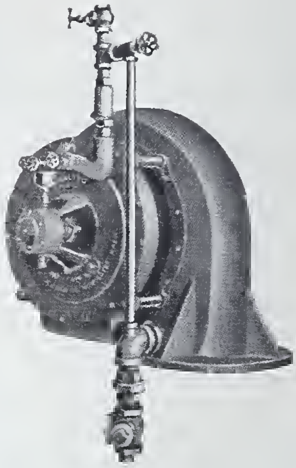


FIG. 151.—CARLING DOWN-DISCHARGE TURBO BLOWER AS USED FOR LOCOMOTIVE FIRING.

[*The Carling Turbo Blower Co.*

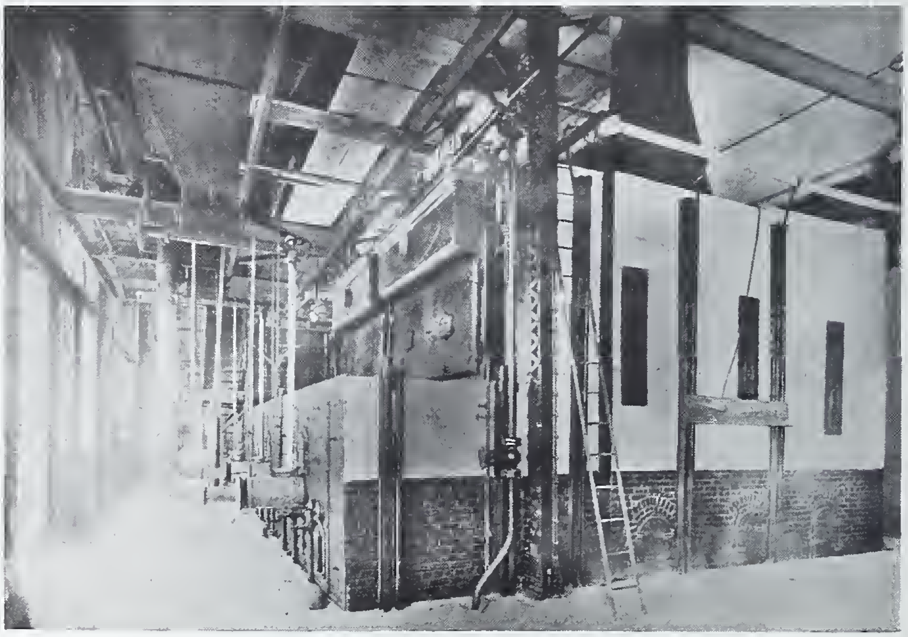


FIG. 152.—O'BRIEN BOILERS AT PARSONS, KANSAS, ONE OF THE FIRST RANGE OF BOILERS TO BE PULVERISED-COAL FIRED, SHOWING FULLER FEEDERS AND BURNERS.

CHAPTER XIII

THE APPLICATION OF PULVERISED COAL TO STEAM BOILERS

COST OF BOILER-HOUSE INSTALLATIONS—STEAM BOILER EFFICIENCIES—THE BURNING OF HIGH- AND LOW-VOLATILE AND WASTE FUEL—ORIGINAL BOILER TESTS WITH LOW-GRADE FUEL—MILWAUKEE AND OTHER SUPER-POWER STATIONS—THE 2600 H.P. BOILERS AT RIVER ROUGE—LIMITATIONS OF MECHANICAL STOKERS—INTERNAL FIRE TUBE BOILERS—LOSS OF COMBUSTIBLE IN CLINKER: WASTAGE WHILE "BANKING"—COMBUSTION CHAMBER AREAS —SMALL POWER STATIONS—SELF-CONTAINED UNITS AND WATER-JACKETED COMBUSTION CHAMBERS—THE BETTINGTON BOILER—REMOVAL OF ASH

DURING the past few years much progress has been made in the application of pulverised coal to the firing of steam boilers. The many and serious difficulties previously encountered have been overcome, one of the greatest achievements of the last few years being the satisfactory elimination of the ash problem. Metallurgical furnaces offered an easier field in which to investigate these difficulties, and on that account greater strides have been made in application to melting and heat-treatment furnaces than to steam-raising plant. The advances made in the proper control of gas velocities, combustion areas, and methods of dealing with ash and slag in metallurgical furnaces gave the clue to the solution of the ash and slag difficulty in connection with steam boilers.

At first, isolated tests on single or two-boiler units were run at several American works, and, in course of time, the first comprehensive coal-pulverising plant for purely boiler-house fuel supply was installed. This was at the repair shops of the Missouri, Kansas and Texas Railway, where eight O'Brien boilers were fitted with pulverised coal burners. See Fig. 152.

In consequence of the good results shown at several installations, Messrs. Stone and Webster, consulting engineers, of Boston, Mass., introduced this system some three years ago at the power station of the Puget Sound Traction Co. The boiler capacity of this station is 4100 h.p., and this departure may be taken as having been the first decisive step in the direction of using pulverised coal in the boiler-house of a public supply power station.

When first applying pulverised coal firing to existing water-tube boilers, much trouble was experienced owing to the formation of solid accumulations of slagged ash, both on the boiler tubes and in the combustion chamber. Slag formation on the boiler tubes was the first to be overcome by proper attention to the combustion area, velocity of gases, and fine pulverisation of the fuel. But the problem presented by the heavy formation of sticky or solid slag in the combustion chambers long remained unsolved; in fact, it is only quite recently that positive means have been found of retaining the ash formation in a friable or dry state.

By the provision of air inlet ports at or about the slag line of a boiler combus-

tion chamber, the falling ash can be cooled below fusing point and so remain " dry " for easy removal. Air entering through these " ash cooling " ports is but a small proportion of the air required for combustion of the fuel, and does not affect the efficiency of the system.

The point at which fusion of ash takes place has a decided bearing upon this question, so that with certain grades of coal the difficulties of slag formation will be greater than with other kinds of coal. (See p. 67 for further information on this subject.)

In view of these early troubles experienced with slag formation, Bettington designed his special vertical water-tube boiler for use with pulverised coal. In this design special provision was made for running off the ash slag in liquid form.

R. Turnbull Mawdesley, in an article on the equipment of the municipal electric supply station of Johannesburg, S.A., makes reference to the Bettington boilers installed at this plant (see *Electrical World*, March 11th, 1916). In his article Mawdesley sums up the advantages of using pulverised coal as follows :—

"It is possible to put this boiler on the range within 25 minutes of lighting up from dead cold. As soon as the fuel is shut off the fire is extinguished like a gas jet and there are practically no stand-by losses."

Pulverised coal can now be applied with undoubted success to any type of water-tube boiler, and to most types of fire-tube boilers. There is no reason why this method of firing cannot be adopted for Cornish, Lancashire, and, in fact, all types of standard boilers. A boiler such as the Bettington, although no longer necessary in order to obtain perfect results with pulverised coal firing, is, in its re-designed form, a very useful unit, and special reference both to this boiler and the self-contained Bettington pulveriser is made in these pages.

In the progressive steps of applying pulverised fuel it was found, after much experiment, that by cutting down the velocity of hot gases in the combustion chamber to a minimum, the bulk of the ash could be removed before the hot gases reached the boiler tubes. Only a small percentage of the coal ash in the form of dry dust now reaches the boiler tubes and flues. The dust which settles on the boiler tubes is so light and fine that it can be dislodged by blowing with the mouth. A steam jet will clear the deposit in a few minutes, and ash dust in the flues is cleaned out periodically without any difficulty. Liquid slag or caked ash is dealt with in the combustion chamber, the degree of hardness of this ash depending upon its degree of fusibility.

By the use of pulverised fuel the steaming of boilers can be reduced at will, owing to the perfect control of fuel to the burners, so that boilers can be run at 25 % of normal load, if required, remaining ready to take on instantly any load that may be suddenly thrown upon the power station. Quick steaming is a valuable feature of pulverised coal firing. For similar reasons it is economical to run boilers at high rates of overload, and so take on the steam supply of other boilers which may be running light.

The old fears so long held, that pulverised coal as fuel for boilers is unreliable,

dangerous, and undesirable because of ash or dust from the chimneys, can be laid to rest. Replies on these matters are as follows :—

October, 1919.

"Referring to your inquiry relative to the reliability of our boiler installation (thirteen boilers), we are pleased to advise that at no time since this plant was started last February have we had for any reason whatever to shut down any of the boilers due to operation of the pulverised coal plant and the boiler equipment for same.

"We do not hesitate to say that we are not at all, from our experience, liable to have to shut down any of our equipment, which, naturally, would interfere with the operation of our sugar machinery output, which is run 24 hours per day continuously. (Mill pulverising plant run 18 to 20 hours per day, which gives sufficient pulverised coal to operate the boilers 24 hours per day.)"

October, 1919.

"We have been burning 150 tons of coal per day for the last two years in a plant located in the centre of the city."

January, 1920.

"Re your inquiry about what becomes of the fine ash resulting from the burning of pulverised coal under a steam boiler, I have learned to answer this as directly as possible by saying 'I do not know.' (150 tons of coal burnt per day.)

"We have received no complaints, and can find no evidence round about that would indicate that our ash descends anywhere in the vicinity.

"I do not think I can say anything more practical or definite than to reiterate that the disposal of ash has not been one of our troubles."

January, 1920.

"We have made some few changes, and are now running very smoothly, and the installation is very satisfactory in every way, both as to the reliability of the pulverising plant and also to burning the coal (bituminous sludge) underneath the boilers. We will probably instal one more 600 h.p. boiler in the coming year, and it will be under powdered coal, the same as the rest.

"We have had no trouble with the furnaces since starting to burn this sludge, nor have we had any trouble with the boilers, as the tubes have stayed clean all the time."

Cost of Boiler-House Installations.

The figures given in the following table indicate the approximate present-day cost of boiler-house installations of various capacities, and afford a guide to the relative additional expense incurred by pulverising and burning coal. Generous allowance has been made, when compiling this table, to cover normal incidental expenses.

Table showing Plant, Equipment, Overall Costs and Operating Expenses per Ton of Coal, Pulverised and Burned (*Electrician*, Sept. 1920).

Normal working output in tons per day (24 hours).*	Costs per ton of coal pulverised, conveyed and burned.							Capital outlay.			Number and rating (lb. per hour) of boilers, included in estimate.	Total output of all boilers, lb. water evaporated per hour at 79% efficiency.¶	Value of fuel savings per year using coal at 35s. per ton.**		Normal working output in tons per day (24 hours).
	Labour cost at £3 10s. per man per week.†	Total power cost at 1½d. per unit for power.‡	Cost of fuel for dryer using coal costing 35s. per ton.	Cost of repairs.	Interest on initial outlay, at 6%.§	Depreciation on plant, including building, at 10%.§	Total cost. Pulverising, transporting, burning and power for air fans.	Approximate cost of mill-house plant with buildings.‖	Cost of boiler equipment for boilers, as specified.‖	Total cost of complete plant.‖			Mechanical stokers, 20% reduction in fuel.	Hand firing, 33⅓% reduction in fuel.††	
	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	£	£	£			£	£	
30	1 8½	3 1½	0 6½	0 4	1 1	1 10	8 7½	6,600	1,500	8,100	3/8,000	23,000	30	2,550	30
40	1 10½	3 1½	0 6½	0 4	0 10	1 4	8 0½	6,600	1,500	8,100	3/9,000	30,000	400	3,800	40
50	1 0½	3 1½	0 6½	0 4	0 9	1 3¼	7 0¾	7,500	2,000	9,500	4/8,000	38,000	1,000	5,200	50
60	0 10½	3 1½	0 6½	0 4	0 7½	1 0½	6 6½	7,500	1,800	9,300	3/15,000	46,000	1,500	6,600	60
70	0 8¾	3 1½	0 6½	0 4	0 6¾	0 11¼	6 2¾	7,500	2,350	9,850	3/18,000	53,500	2,300	7,900	70
80	1 1	3 1½	0 6	0 4	0 6	0 10	6 4½	7,500	2,350	9,850	4/15,000	61,000	2,300	9,000	80
90	0 10¼	3 1½	0 6	0 4	0 7½	1 1	6 6¼	11,200	2,800	14,000	4/20,000	69,000	2,600	10,000	90
100	0 9¼	3 1½	0 6	0 4	0 7	0 11¾	6 3½	11,200	3,500	14,700	4/25,000	76,500	3,000	12,100	100
125	0 5	3 1½	0 6	0 4	0 5¾	0 9½	5 7¾	11,200	3,500	14,700	4/25,000	95,000	4,700	15,000	125
150	0 6	3 1½	0 5½	0 4	0 5	0 8¼	5 6¼	11,200	4,350	15,550	5/25,000	115,000	5,800	18,200	150
200	0 4½	3 1½	0 5½	0 4	0 5	0 8¼	5 4¾	15,000	5,300	20,300	6/25,000	153,000	8,400	24,200	200
250	0 5½	3 1½	0 5½	0 4	0 4¼	0 6¾	5 3½	15,000	6,500	21,500	6/32,000	190,000	10,200	30,200	250
300	0 4½	3 1½	0 5½	0 4	0 4¼	0 7	5 2¾	18,000	8,700	26,700	8/30,000	230,000	12,500	37,000	300

* Average operating time of mills not more than 20 hours per day, but operating time of boilers taken as 24 hours per day.

† Labour charges based on 5½ working days per week, and maximum working day of 8 hours per man.

‡ Power taken at 25 kw. hours per ton to cover all power from raw coal to completed combustion in furnace.

§ Interest and depreciation based on 300 working days per year.

‖ Cost of plant given above is based upon prices for equipment made in America F.O. Cars New York Harbour, and based on an exchange rate of $4·82 per £1 (normal exchange)

¶ Calculated on the following conditions: Steam pressure 150 lb. sq. in., feed temperature 150° F., superheat 150° F., and coal 12,500 B.Th.U. per lb.

** Price of raw coal taken at 35s. per ton, and in case of pulverised coal firing, the total overall preparation cost for the corresponding size of plant as given above has been added to the cost of raw coal.

†† It is realised that the larger boilers could not be conveniently hand fired.

Any efficient and proved type of machinery can be accepted for the coal-crushing, drying, and milling machinery, and the only essential point to bear in mind in regard to the application of pulverised fuel supply to boilers is to maintain an 8 or 10 hours' supply in bunkers at the actual boilers. Screw feeders are attached to the outlets from these bunkers in order to supply the powdered fuel to the air blast at a point as near as possible to the burner pipes entering the walls of the combustion chambers. In this way there is no possibility of igniting a large volume of explosive mixture prior to actual combustion in the furnaces.

This reserve fuel-supply system is the only rational arrangement that can be put forward with any degree of confidence for power-house boiler firing, where continuity of steam supply is of such vital importance. Reference to the list of American boiler installations recorded by Barnhurst and Scheffler in the information given by them to the American Institute of Electrical Engineers, shows that there is not one single case where the pulverised fuel storage method at the boiler has not been adopted.

Steam Boiler Efficiencies.

On the question of fuel consumption and boiler efficiencies, the British Ministry of Munitions' final report (1920) of the Nitrogen Products Committee contains a mass of interesting data relative to steam power generation for stations of 125,000 kw. capacity.

It is therein clearly shown that with coal at 7*s*. 6*d*. per ton (and the lower the price of coal the greater advantage accrues to by-product recovery processes) the direct firing of boilers with coal is far more economical than applying producer gas, so far as actual overall cost of fuel application is coneerned, and that an average working efficiency of 80 % is a standard that can be reached only for stations having a constant 95 to 100 % load factor. Normal city power-station loads vary considerably throughout the 24 hours, and a power factor of 60 % is considered good. Under normal power-supply conditions, the best average working efficiency, due to banking losses, clinker formation on stokers, excess air supply under forced draught, etc., cannot be any higher than 70 %. With pulverised coal firing it would be quite possible to maintain an average working efficiency of 78 to 80 %.

When calculating boiler efficiencies, much depends upon the sample of fuel forming the basis of calculation. Under ordinary boiler-house conditions such samples may well be unduly moist, or may have become contaminated with ash; thus an incorrect figure is returned for the apparent calorific value of the coal used. Samples of pulverised coal as fired are perfect samples of the fuel used, for it will be conceded that no better method ean be suggested for their preparation. With this system of boiler firing, steady working efficiencies of 75 to 80 % can be maintained for all loads, from 25 % of full load to double and treble maker's rating, and for any length of time. Mechanical stokers cannot possibly be worked at the latter duty for any long period at a stretch. Pulverised coal firing has the same advantages, almost, as oil firing, in regard to flexibility of firing and heavy continuous overload duty.

When dealing with coke-fired boilers the Nitrogen Products Committee suggests

a figure of 70 to 75% for average working efficiency with superheaters and economiser. With pulverised coke, especially the product of low-temperature carbonisation, efficiencies equal to coal-firing could be readily obtained.

To substantiate this assertion it may be mentioned that 82 % efficiency has been realised at the Susquehanna Collieries in America when burning anthracite culm containing no more than 5% of volatile matter and up to 30% ash. "Low Temperature" low ash coke, therefore, would be an ideal fuel for pulverisation, and it is hoped that this method of applying coke as fuel will assist towards the more rapid development of combined by-product recovery distillation plants and electric power generating stations.

The Burning of High- and Low-Volatile and Waste Fuel.

Pulverised coal can be applied to boiler furnaces through horizontal or vertical burners. The Fuller Engineering Co. advocates the burning of bituminous coal and lignite by means of horizontal burners, and when fuel of low volatile content is to be burned, the vertical burners are recommended. Illustrations of four standard types of water tube boilers as equipped respectively with horizontal and vertical burners on the Fuller principle are shown in Fig. 153.

Individual water tube boiler units Babcock and Wilcox, and of the Stirling type, as arranged for pulverised coal firing and showing the standard arrangement of fuel bins, feeders and burners of the Fuller design, are shown in Figs. 154 and 155.

Not only is it possible to burn high-grade coal at a combustion efficiency figure approaching 100%, but a wide range of "waste fuel" can also be burned in this manner. Some notes by C. M. Rau, concerning the burning of anthracite waste, for instance, appeared in *Power*, November 29th, 1921, to the following effect :—

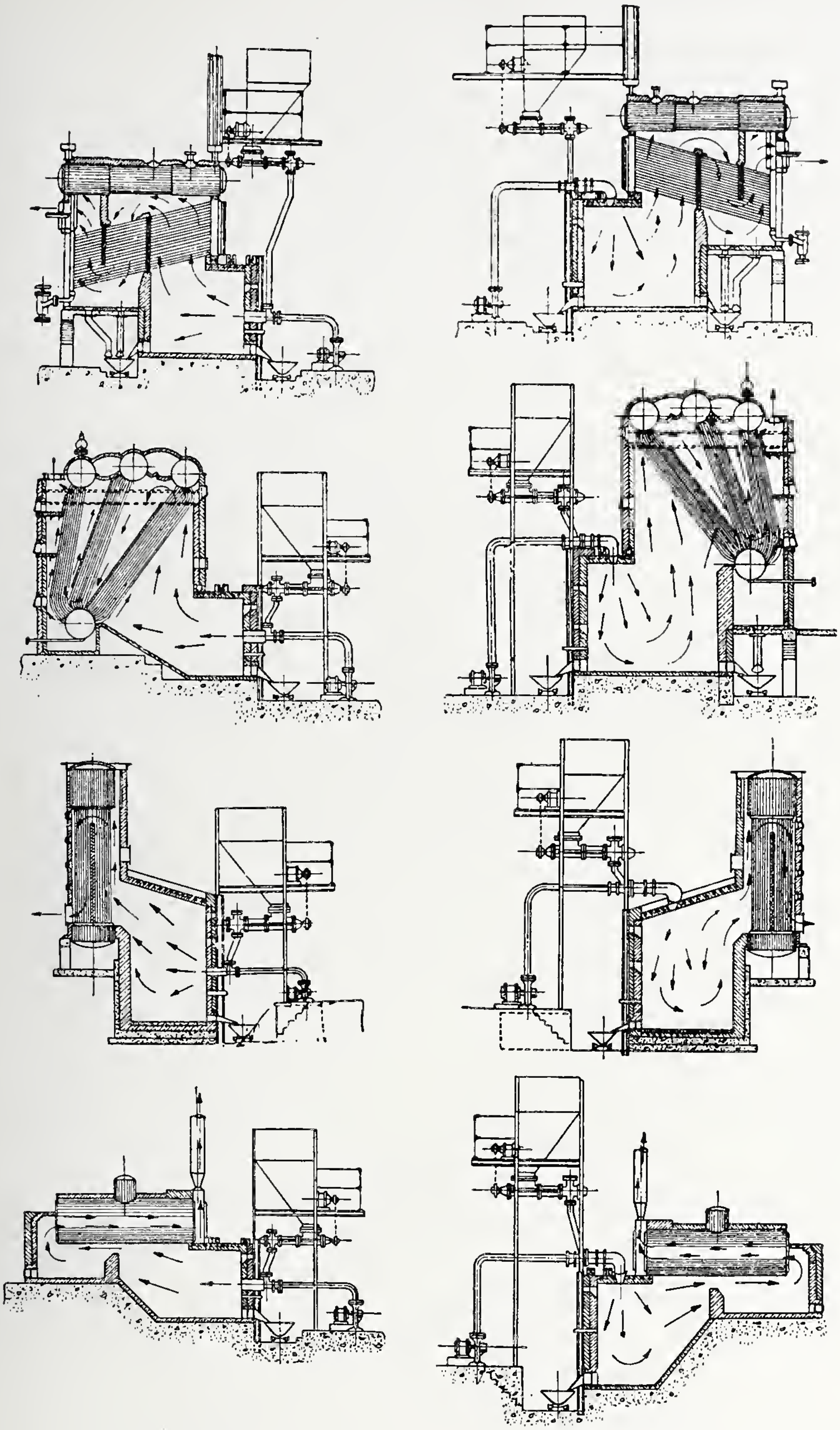
Accumulation of culm from anthracite mines has been going on for years, until mountains of this material have formed in mining regions. Estimates of the total tonnage of these accumulations vary from fifty to one hundred million tons of recoverable coal.

The large percentage of non-combustible in waste culm and the difficulty of pulverising to a fineness that would assure efficient combustion were the outstanding obstacles. (The application of the Minerals Separation and Trent processes, see p. 108, makes possible a reduction of ash to any predetermined amount.)

The pulverising of anthracite culm, silt, or river coal was found to be attended with difficulty, and considerably more expense, than the cost of pulverising bituminous or other soft coal.

Tests were made with various types of mills, and the action on mills of the Fuller, Raymond, tube and pebble types was noted, with the result that it was found to be commercially feasible on a basis of a mill capacity of one-half that obtained with bituminous coal and with about double the maintenance expense.

After preliminary studies, the Philadelphia Rapid Transit Co. approved a trial pulverised-coal installation in its Thirteenth and Mt. Vernon Street power plant. The plant consisted of 20 B. & W. boilers each having 3917 sq. ft. of water-heating surface. The fuel previously in use was No. 1 anthracite buckwheat at \$3·50 per ton; when this coal increased to \$5·00, and finally reached a price of \$8·00 per ton,



Horizontal Burners. Vertical Burners.

Fig. 153.—Typical Arrangements of Boilers Equipped with Fuller Horizontal and Vertical Burners as recommended for burning "soft" and "hard" fuel respectively.

(*The Fuller Engineering Co.*) (*The Fuller Lehigh Company.*)

the plant was restricted to peak-load service. This resulted in a considerable expense for coal to maintain fires (hand-fired grates) between peak periods, and, in consequence, the cost per kilowatt hour became excessive. It was decided to introduce pulverised coal firing.

The boilers are set in two rows of ten each with a stack midway in each row. Only ten boilers on the north side of the stacks were selected to be equipped for burning pulverised fuel, since it was seen that the increased rating, over hand firing, at which the boilers could be operated with this fuel would give ample steam to operate the plant at full capacity.

In the boiler-room the principal changes consisted of placing dust-tight partitions in the existing Berquist-type coal bunker, so that each boiler could have its own pulverised-coal storage bin with a capacity of approximately 25 tons. Beneath the coal bunker and supported therefrom, twenty Quigley screw-type pulverised-coal feeders (two for each boiler) were installed. These were driven from a shaft extending the full length of the bunker and operated by a 15 h.p. motor arranged for duplicate installation in case of motor trouble. Each feeder is equipped with a clutch engaging with a chain drive to the main shaft.

The furnace changes consisted of combining the former combustion chamber and ashpit, and extending this space in front of the boiler so as to form one large combustion chamber; into this chamber the Quigley burners enter at an angle through the top of the extended portion in front of the boilers. The total volume of each combustion chamber, as reconstructed, is 1542 cu. ft.

Two 14-in. burners are required for each boiler. The fuel is fed into the burners through two $3\frac{1}{2}$-in. pipes.

To ensure rapid ignition of the anthracite when putting a boiler into service, which, owing to the low percentage of volatile in this kind of coal, does not ignite as readily as bituminous coal, the furnaces were equipped with two oil burners. Owing to the similarity of combustion chamber areas and of the arrangements for burning oil and pulverised coal, the use of oil as a fuel can be resorted to when necessary with very efficient results, an advantage not possible when furnaces are fitted with other means for burning coal. The amount of oil required to ignite the pulverised coal varies from 30 to 40 gallons when starting with a cold boiler, and 10 to 20 gallons between peak-load operation periods.

The pulverised-coal production plant consists of two high side Raymond mills, one Ruggles-Coles dryer and a Quigley air-transport system.

Some successful results when burning pulverised anthracite as a boiler fuel have been recorded in France at the Mines de Blanzy (Quigley system) and at the Mines de la Muir (Bergman system), and at the latter mines, Bergman, in 1921, demonstrated that waste anthracite fines of less than 2 mm. mesh could be burned in pulverised form under semi-water tube boilers. The arrangement of the combustion chamber and the direction of the flame from the burner should be noted, for it is essential when burning low-grade low-volatile fuel to return the flame on to the incoming mixture, in order to raise the carbon particles to the required ignition point.

Approved methods of burning bituminous high-volatile coal and anthracite low-

FIG. 154.—FULLER SYSTEM AS APPLIED TO BABCOCK AND WILCOX WATER-TUBE BOILER.

The Fuller Engineering Co.] [*The Fuller Lehigh Co.*

[*To face p.* 258.

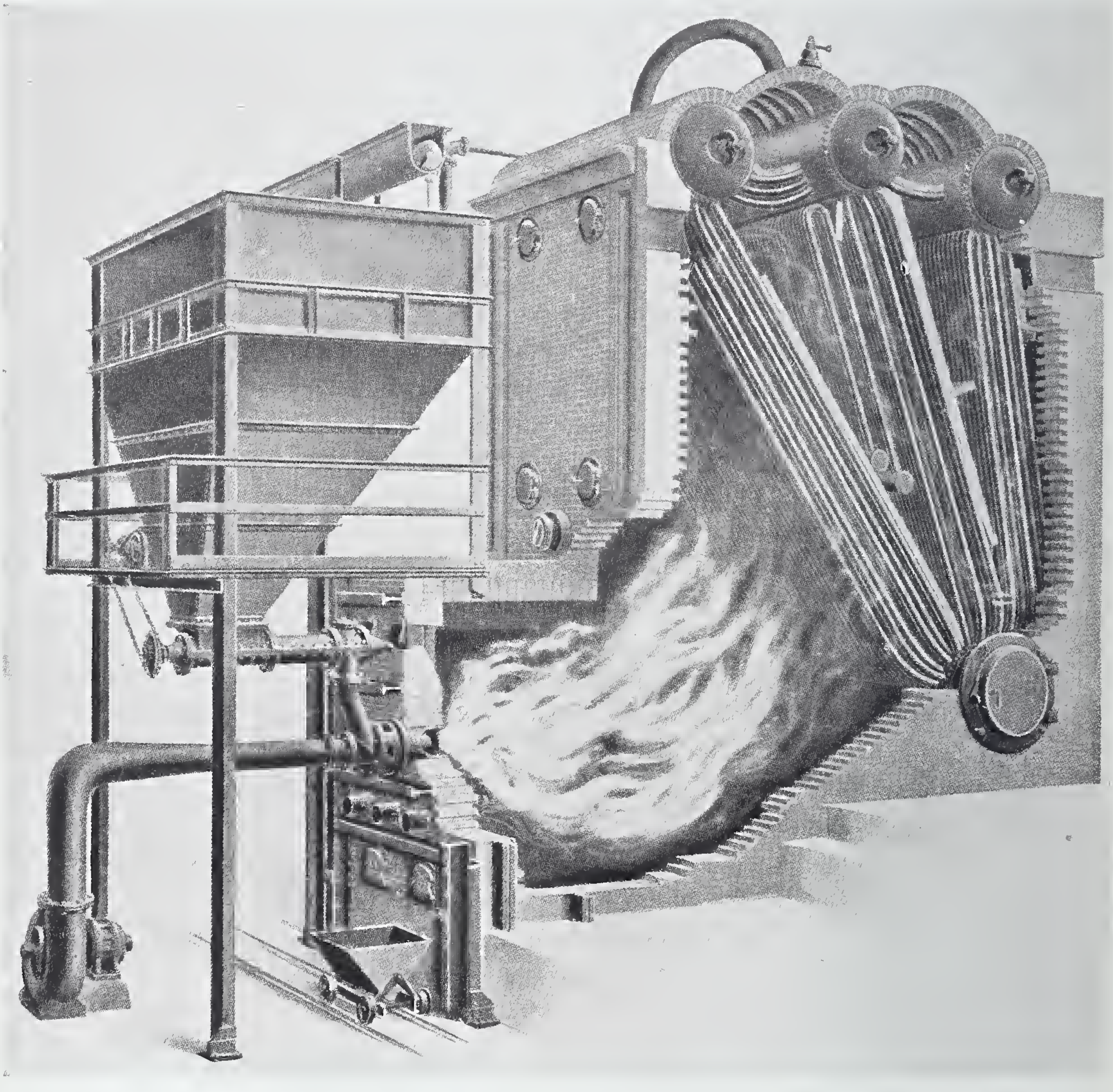


FIG. 155.—FULLER SYSTEM AS APPLIED TO STIRLING WATER-TUBE BOILERS.

The Fuller Engineering Co.] [*The Fuller Lehigh Co.*

volatile coal are shown in Fig. 153, in which the return of the flame on to the incoming low-volatile fuel is clearly indicated.

Fuller burners of the vertical type as used in the latter instance are shown in Fig. 156.

Further reference to the burning of high-ash coal, *i. e.*, colliery waste, has been made by M. Sohm in a paper published in the *Revue de l'Industrie Minerale*, in which an account is given of the extended tests made with a plant which has been in operation for twelve months at the Cie des Mines de Bruay, France. These tests were made after trying to utilise low-grade fuel in gas producers, as briquettes and by means of burning on mechanical stokers.

Complete success has apparently been obtained only by applying this fuel in pulverised form, as indicated by the following figures :—

	Mechanical grate, "Bruay" type.*	Furnace with mechanical stoker.	Furnace burning powdered fuel.
Evaporation per hr. (lb.)	5,642	7,791	7,604
Fuel consumption per hr. (lb.)	1,150	1,338	998
Evaporation per lb. coal (lb.)	4·9	5·82	7·60
Ash content of coal (%)	23·5	22·6	25·3
Calorific value of coal (B.Th.U.)	11,702	11,826	11,453
Approximate amount of coal required to produce 100,000 kw. hr. (tons per day)	195	164	126
Percentage consumption of coal	100	84	64·5

* Movable bars.

The complete pulverising plant has been installed to supply fuel to some thirteen or more boilers, whereas to date only eight boilers have been equipped. The capacity of the plant is sufficient to produce in 16 hours the 150 to 180 tons of coal required per 24 hours. The power consumption for the production, conveying and burning of the fuel under the eight boilers is 19·6 kw. per ton of coal, which figure will be reduced when the full boiler installation is adapted for burning pulverised coal.

Original Boiler Tests with Low-Grade Fuel.

As a record of the early tests made at the repair works of the Missouri, Kansas and Texas Railway the following notes have been extracted from *Metallurgical and Chemical Engineering*, September 15th, 1916.

When, during the winter of 1912, the natural gas supply was limited in quantity and fuel oil hard to obtain in Kansas, the Missouri, Kansas and Texas Railway Company officials decided to investigate other methods for generating steam in their boilers at the power house of their new shops at Parsons, Kan., where eight 250 h.p. O'Brien boilers, Fig. 152, of the Heine water-tube type were installed, with equipment for using only natural gas and oil fuel. Some of the other fuels available

in the district which would be within an economical range as to cost delivered at their plant, were soft coals from the mineral mine in Kansas, McAllister and Lehigh mines in Oklahoma, and lignite from Texas, having the following Government analyses :—

Kind of Coal.	Fixed Carbon.	Volatile Matter.	Ash.	Moisture.	B.Th.U. Value.
Mineral	45·22	26·39	20·38	8·01	10,640
McAllister	47·07	32·37	14·29	6·27	11,837
Lehigh	41·40	31·28	19·29	8·03	11,200
Lignite	25·50	33·95	7·58	32·97	7,548

The sulphur, separately determined, ranged from approximately 3 to 5 % in the various soft coals.

The plant was put into successful operation on August 1st, 1916. Various tests were made with the different fuels mentioned above, and all of them were burned with entire success, showing exceptional heat-absorptive effects throughout the heating surface of the boiler with low stack temperatures. No deposit of ash settled anywhere in the boiler but what was readily dislodged with an ordinary air blast. The evaporation obtained with 16 % CO_2 in the stack was 10·7 lb. of water per lb. of combustible at and from 212°.

A *résumé* of the tests carried out on these boilers by Joseph Hartington, combustion engineer, Chicago, was printed in *Power*, September 11th, 1917, and is given below :—

Tests on Boilers at the Missouri, Kansas and Texas R.R. Shops at Parsons, Kansas, Fired with Pulverised Coal.

No. of Test.	Kind of Coal.	Rated Boiler Horse-power.	Duration of Test, Hours. (hr. min.)	Steam Pressure by Gauge, Lb.	Temperature of Feed Water, ° F.	Factor of Evaporation.	Flue-Gas Analysis. CO_2 %	O %	CO %	N %	Prox. Analysis Dry Coal. Vol. %	Fixed Car. %	Ash. %	Equiv. Evap. from and at 212 per Lb. Coal as Fired.	Equiv. Evap. from and at 212 per Lb. of Dry Coal.
1	Cherokee Mineral Slack . . .	191	1 0	126	177	1·0795	12	8	0	80	28	49	22	6·32	6·38
2	Texas Lignite .	191	2 4	127·4	183·6	1·0728	10	10	5	79·5	42·5	32	9·5	7·17	8·54
3	McAllister . .	191	2 12	127	180	1·0764	10	9·5	0	80·5	31·3	50·1	15·1	8·77	8·85
4	Texas Lignite .	191	1 30	118·1	182	1·0736	10	11	0	79	47·1	35·4	10·5	7·31	7·86
5	Texas Lignite .	161	1 13	130·6	182·5	1·0743	12·5	8·5	0	79	47·1	35·4	10·5	7·26	7·81
6	Cherokee Mineral Slack . . .	382	1 24	126	170	1·0867	10	11	0	79	28·4	48·7	21·9	7·18	7·27
7	Cherokee Mineral Slack	191	2 0	123	187	1·06875	13·5	7·5	0	79	28·4	48·7	21·9	6·9	6·97
8	Cherokee Mineral Slack	191	6·58	126·6	174·4	1·0822	10·7	9·3	0	80	28·4	48·7	21·9	8·38	8·46
9	Texas Lignite .	191	4·30	137·5	166·9	1·0562	14·75	5	0	81·16	61·52	24·72	13·76	4·953	6·305
10	Cherokee Mineral Slack . . .	191	4·0	135	165·8	1·0559	14·8	3·5	0	81·9	32·41	49·57	18·02	6·824	7·306
11	Kansas Semi-Anth.	191	3·30	135·5	178·1	1·0434	15·8	3·5	0	81·6	22·29	59·94	17·77	8·657	9·061

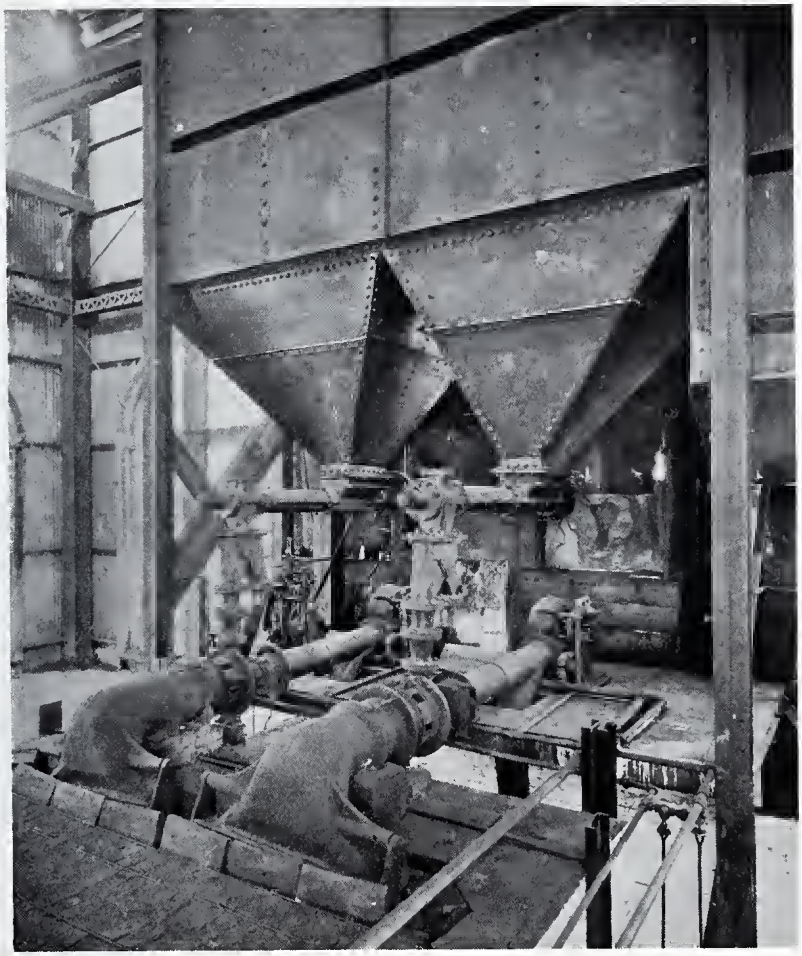


Fig. 156.—Vertical Fuller Burners and Screw Feeders as arranged for Firing Boilers at the Allentown Portland Cement Co.'s Works.

The Fuller Engineering Co.] [*The Fuller Lehigh Co.*

[*To face p.* 260.

No. of Test.	Kind of Coal.	Combined Efficiency Boiler and Furnace.	B.Th.U. per Lb. Dry Coal.	Draft.			Temperature of Flue Gases, °F.	Total Wt. Coal as Fired, Lb.	Moist. in Coal as Fired, %.	Total Dry Coal Fired, Lb.	Total Combustible, Lb.	Equiv. Evap. from and at 212 per hour.	Per cent. Rated Capacity Developed.
				At Air Inlet in.w.g.	In Furnace in.w.g.	At Boiler Damper in.w.g.							
1	Cherokee Mineral Slack . . .	53·9	11,580	$\frac{3}{4}$	—	0·25	544	1,014	1	1,004	781	6,420	97
2	Texas Lignite .	75·5	11,250	$\frac{9}{16}$	—	0·28	491	1,927	16	1,620	1,437	6,690	101
3	McAllister . .	67·8	12,630	$\frac{3}{4}$	—	0·28	585	2,062	$\frac{1}{2}$	2,051	1,739	8,240	120
4	Texas Lignite .	67·8	11,250	$\frac{5}{8}$	—	0·262	473	1,746	7	1,623	1,440	8,520	129
5	Texas Lignite .	67·4	11,250	$\frac{3}{4}$	—	0·265	501	1,612	7	1,500	1,330	9,550	143
6	Cherokee Mineral Slack . . .	61·0	11,380	$\frac{3}{4}$	—	0·242	470	3,540	1	3,500	2,730	17,450	138
7	Cherokee Mineral Slack . . .	59·0	11,580	$\frac{3}{4}$	—	0·256	576	3,560	1	3,525	2,745	12,280	186
8	Cherokee Mineral Slack . . .	71·5	11,580	$\frac{3}{4}$	—	0·23	446	6,617	1	6,560	5,100	7,950	125
9	Texas Lignite .	57·32	10,675	0·55	0·082	0·092	581	6,748	17·06	5,598	4,825	7,844	119
10	Cherokee Mineral Slack . . .	58·00	12,185	0·41	0·051	0·055	534	4,692	1·06	4,644	3,808	8,482	129
11	Kansas Semi-Anth.	69·64	12,625	0·40	0·058	0·000	624	3,500	0·3	3,489	2,868	9,034	137

Scheffler and Barnhurst, in a paper read at Detroit in June, 1919, before the American Society of Mechanical Engineers, gave an instructive list of boiler tests made at several American works with various low-grade qualities of small or waste coal, and lignite, and the following table has been taken from this paper :—

TESTS CARRIED OUT ON AMERICAN PULVERISED COAL-FIRED BOILERS USING BITUMINOUS COAL AND ANTHRACITE SMALL OR WASTE COAL.

Date of test.	Location of plant.	Duration, hr.	Coal used.	Efficiency maintained, %.	B.Th.U. per lb. of Coal as fired.	Ash %.	Rating %.
Apr. 16, 1917	Seattle, Wash.	14·5	Renton buckwheat	77	10,000	11·60	122
Dec. 4, 1917	Chanute, Kan.	5	Kansas bituminous	72	11,996	17·7	125
Dec. 12, 1917	Chanute, Kan.	5	Kansas bituminous	83·94	12,500	18·25	125
Jan. 28, 1918	Chanute, Kan.	(25 days)	Kansas bituminous	78·1	11,435	—	100
Apr. 26, 1918	Parsons, Kan.	6	Kansas bituminous	80·3	12,900	17·49	—
Apr. 28, 1918	Parsons, Kan.	6	Kansas bituminous	80·9	12,289	17·49	130·8
June 14, 1918	Milwaukee, Wis.	12	Illinois and Indiana screenings.	83·3	10,897	15·89	117·7
Nov. 5, 1918	Lykens, Pa.	10	Lykens No. 3 buckwheat anthracite.	84·2	12,530	16·92	135
Nov. 15, 1918	Lykens, Pa.	5	Lykens slush buckwheat anthracite.	81·2	13,653	11·09	142
Nov. 22, 1918	Lykens, Pa.	5	Lykens slush buckwheat anthracite.	85	12,753	18·04	146
Nov. 23, 1918	Lykens, Pa.	5	No. 3 buckwheat anthracite.	72·7	12,530	16·91	115
Dec. 2, 1918	Lykens, Pa.	5	Lytle slush anthracite.	75·3	12,753	23·92	188
Feb. 1, 1919	Seattle, Wash	24	Issaquah screenings	78·95	11,660	14·31	126
Feb. 2, 1919	Lykens, Pa.	4	No. 3 buckwheat anthracite.	78·9	13,067	14·02	177
Apr. 7, 1919	Vancouver, B.C.	4	Nanaimo slack	83·3	9,364	28·4	125
Apr. 17, 1919	Vancouver, B.C.	5	Nanaimo slack	77·1	10,050	24·3	160
Feb. 3, 1919	Lykens, Pa	5·5	No. 3 buckwheat anthracite.	78·9	12,530	14·00	—
Sept. 24, 1918	Verde, Ariz.	(6 days)	Gallup, New Mexico	79·5	10,680	14·31	155

Typical test figures for a boiler plant installed at an industrial works, fired with pulverised bituminous coal containing a high percentage of ash, are given below. This is a specific instance where the prior washing of the coal (see Chap. VI) would be more profitable than the grinding of so much inert material.

Boiler Test at Vancouver, B.C.

Date: April 7th, 1919.
Location: B.C. Sugar Refining Co., Ltd., Vancouver, B.C.
Make and Type of Boiler: Badenhausen Vertical Water Tube.
Object of Test: Efficiency; Rate of Evaporation; General Results.

Fuel

Kind: Vancouver Island; Nanaimo; Bituminous; Slack.
Analysis: Moisture of 1·1 %; Volatile Carbon 32·8 %; Ash 28·4 %; B.Th.U. 9634.
Pulverised: 81·1 % through 200 mesh; 95·25 % through 100 mesh.
Weight of Coal as Fired: 16,824 lb.

Water

Weight of Water Fed to Boiler: 122,345 lb.
Temperature Feed Water entering Boiler: 177°.
Temperature Feed Water entering Economiser: 85° F.

Steam

Pressure by Gauge: 71 lb.
Temperature at Gauge Pressure: 317° F.
Superheat: Boiler designed for 10° or 12° superheat, but not considered in this test.
Factor of Evaporation: 1·160.

Hourly Rates

Dry Coal per hour: 2763 lb.
Water per hour actual: 20,390 lb.
Water per hour F. and A. 212°: 23,652 lb.
Evaporation per hour per sq. ft. Water-Heating Surface: 4·32 lb.

Capacity

Boiler h.p. Developed: 727 h.p.
Rated Boiler h.p.: 600 h.p.
Percentage of Rated Capacity Developed: 122 %.

Economy Results

Actual Evaporation per lb. of Coal as Fired: 7·27 lb.
Equivalent Evaporation per lb. of Dry Coal, from and at 212°: 8·53 lb.
Equivalent Evaporation per lb. of Combustible, from and at 212°: 11·93 lb.

Efficiency

Combined Boiler and Furnace Efficiency Based on Coal as Fired : 85·0 %.

Flue Gases

Temperature of Escaping Gases from Boiler : Average 500°.
Temperature of Escaping Gases from Economiser : 385°.
Analysis of Gases CO_2 by recording apparatus : Average 13 %.
Analysis of Gases O by Orsat apparatus : 6 to 8 %.
Analysis of Gases CO by Orsat apparatus : None.
Smoke : Very light white haze.
Draft : Over fire $\frac{1}{4}$ in.; At stack $\frac{5}{8}$ to $\frac{3}{4}$ in.; Induced Draft.
Furnace Temperature : 2200° to 2540°; average 2425°.

Milwaukee and other Super Power Stations.

At the close of the year 1918, American engineers were convinced, following upon the successful development of pulverised coal applications in the iron, steel, and copper industries, and also in view of the proved economies resulting from the use of this fuel for steam raising, that greater attention should be given to this method of firing power-house and industrial boiler plants in the near future. And, it was not long after, that the Milwaukee Electric Traction and Light Co. decided to equip the first unit of 40,000 kw. at the new 200,000 kw. capacity super-power station in that city with boilers to be exclusively fired with pulverised coal. Subsequently the system was extended to the second unit of 60,000 kw.

The illustration shown in the plate facing p. 264 has been reproduced from *Power* of December 19th, 1922, and depicts the power-house on the left and the coal-preparation building on the right of this general sectional view. The plant was put into service in the early part of 1921.

For the first 40,000 kw. capacity there are at this station eight 1306 h.p. Edge Moor boilers, operated at 200 % rating. Three boilers supply steam to one 20,000 kw. turbo generator, thus leaving two boilers normally out of commission. Pulverised fuel bins are arranged above the boilers, as shown in the folded plate and the fuel is fed to the burners by means of screw feeders, six boilers having been originally fitted with the Lopulco feeder mixers, and two boilers with Fuller screw feeders. A sectional view of the Milwaukee Boiler is given in Fig 157.

A description of the equipment used at the Milwaukee power station appears in *Power*, December 19th, 1922, from which article these references are taken.

Pulverised fuel is supplied to the boiler bins by means of Fuller-Kinyon pumps (see p. 220) and the furnace burners used are shown under " Burners " (p. 248).

The furnace bins are rectangular in plan, 30 ft. long by $8\frac{1}{2}$ ft. wide, of steel plate, and have a capacity of 105,000 lb. each. They are lined with concrete, as much because the coal flows better over the concrete surface as for preserving the metal. There has never been any tendency observed at Lakeside for the coal to ignite spontaneously or even to heat unduly in the bins.

To the hopper-shaped bottom of each bin are attached three Lopulco duplex

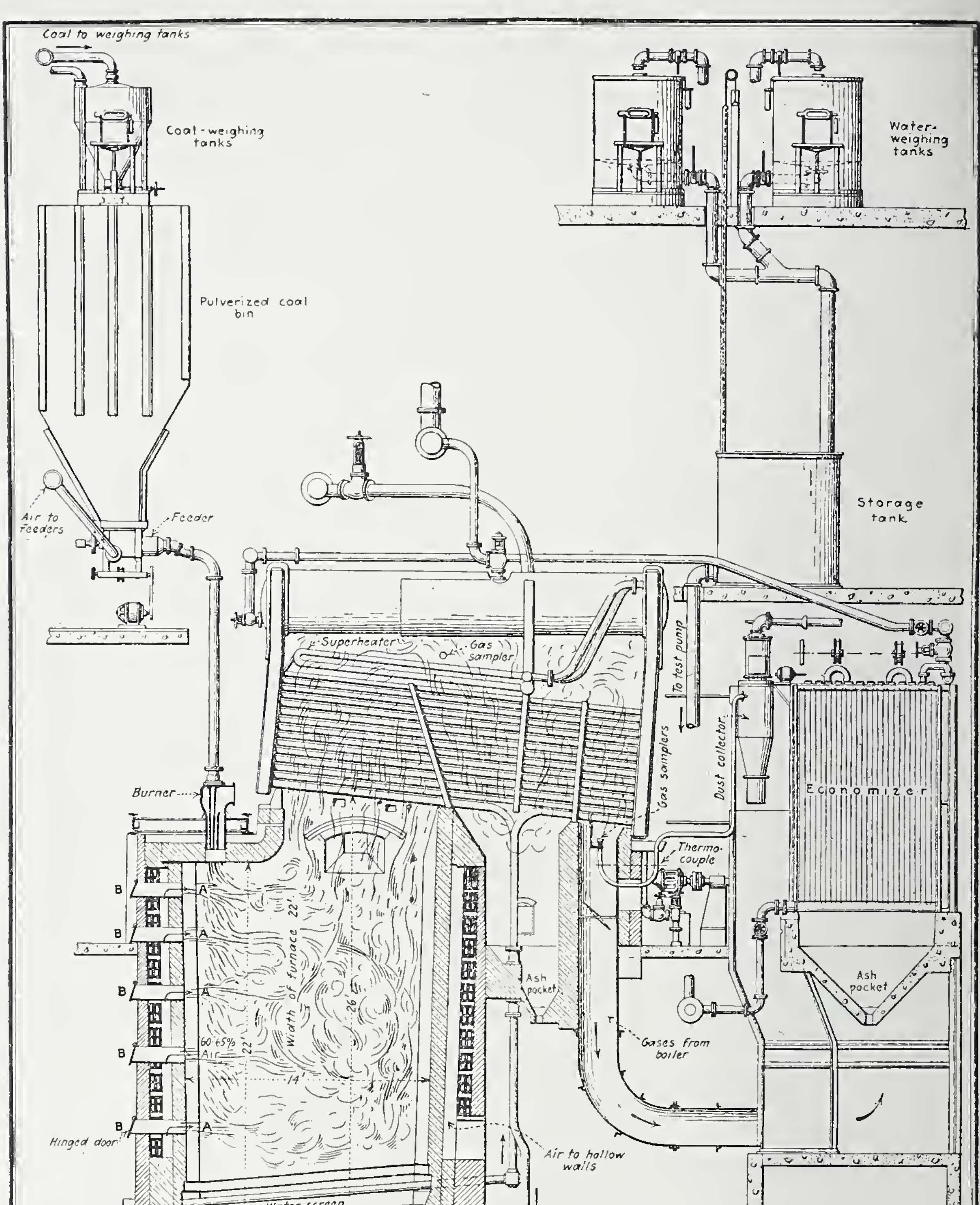


FIG. 157.—Section of Pulverised Coal Fired Boiler at the Lakeside Station, Milwaukee Electric Railway and Light Company, showing Lopulco Burners and Coal Weighing Tanks. (*Power*, December 1922.)

Lakeside Generating Station

of the

Milwaukee Electric Railway & Light Company

Operated Exclusively by Pulverized Coal

Initial Rating, 40,000 Kw.

Ultimate Rating, 200,000 Kw.

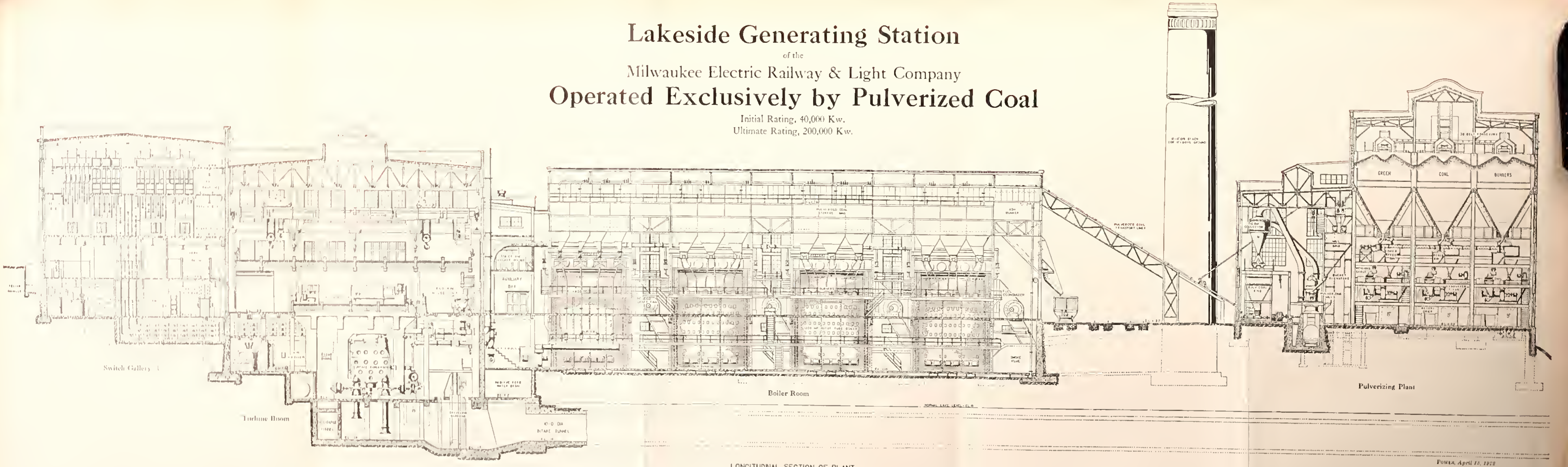


Fig. 157a.—Longitudinal Section of Plant.

The first great advance in the application of Pulverised Coal Firing to Public Supply Super Power Station Boilers—showing Fuller Air Separator Pulveriser Mills, Fuller-Kinyon Fuel Delivery Pumps—Fuller Screw Feeders and Horizontal Burners on one Boiler, and Lopulco Feeder Mixers and Vertical Burners on Three Boilers. Subsequent Lopulco Installations at St. Louis, Cleveland; Detroit; Pittsburg; Springdale; Providence; Rochester; St. Paul; Middletown; Valmont; and Peoria, in the United States of America, Vitry (Paris) and Tokio (Japan).

[To face p. 264

feeders (see p. 244). Each feeder is driven through a Reeves variable speed transmission gear (see p. 239), having a ratio of 1 to 5. A 3 h.p. constant-speed motor is used to drive each feeder, and as each feeder supplies two burners, the variation in fuel supply obtainable for each boiler is in the ratio of 1 to 30. Cross sections of the boiler and pulverised coal equipment are shown in Figs. 157 and 158.

The cloud of coal dust entering the furnace at the top front, as indicated in Fig. 158, through six of these burners, ignites, and a cataract of flame flows downward parallel to the front wall. Here it meets a supply of air admitted through the front apertures, of which there are five horizontal rows ten wide, making fifty in all.

As a result of this arrangement there is no scrubbing action of the flame against the front wall, and it does not impinge violently upon the furnace floor, but swirls upward without erosive action on the brickwork. A plot of the temperature gradients shows the temperature near the walls to be 1500° to 2400° F., the zone of maximum temperature being an elliptically-shaped space in the lower centre where the temperature attains some 2800°. The average time afforded for a particle of fuel to pass from the burner through the furnace to the boiler tubes is about two seconds, the flame being U-shaped.

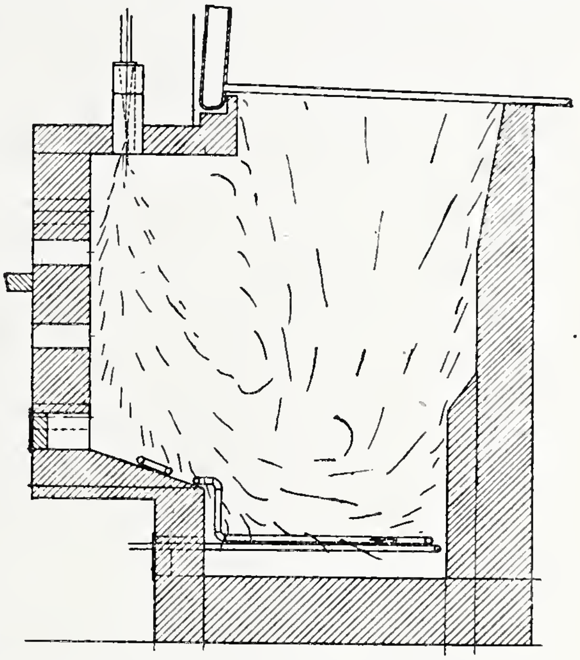


Fig. 158.—Cross section of Furnace, used in U.S.A. Bureau of Mines tests at Milwaukee Generating Station.
(*H. D. Savage.*) (*American Iron and Steel Institute Paper*, May 27, 1921.)

The problem of slagging has been solved by the use of a water screen consisting of a system of 4-in. tubes connected into the circulation of the boiler.

It is stated that "as the quantity of ash from pulverised fuel furnaces is very small and very fine, it is easily conveyed by means of steam jet ash conveyors. A system of steam jet conveyors is installed with main runs leading to furnace ashpits and branches leading to combustion chambers at the rear of boilers and soot pits under the economisers."

Coal is delivered by rail and deposited in the track hopper by means of truck tipplers, whence it is passed through crushers and conveyed by a 36 in. belt conveyor to the raw coal bunker in the pulverising house, this bunker having a capacity of 3400 tons, or approximately 3½ days' supply. The crushers and hammer mills have a capacity of 150 tons of coal per hour; the belt conveyor handles 250 tons per hour at a belt speed of 250 ft. per minute.

Screw conveyors are so arranged that coal can be drawn from any one of three points under the coal bunker and supplied to any one of three rotary dryers, each of 17½ tons capacity per hour when reducing the moisture in the coal from 10

to 1 %. Eight special air-separation Fuller mills were originally installed, each mill having a capacity of 6 tons per hour when driven by motors of 100 h.p.

The pulverised fuel is discharged by the mill exhausting fan into cyclone separators delivering direct on to screw conveyors and collected in bins, from which the fuel is fed into Fuller-Kinyon pumps for despatch to the boiler bunkers.

Full extracts, with test figures, from the technical papers prepared by J. Anderson and P. W. Thompson, in which the deciding factors in favour of the use of pulverised coal for the Milwaukee plant are stated, together with comparison costs for pulverised coal and stoker plant, are given below. These opinions and recorded figures are the most important that have been published on the subject of firing boilers with pulverised fuel, for they result from the investigation of this system of firing extending over a period of two years at the old power station.

EXCERPTS FROM A PAPER ENTITLED "USE OF PULVERISED COAL UNDER CENTRAL STATION BOILERS"

Read by Mr. JOHN ANDERSON, Chief Engineer of Power Plants of the Milwaukee Electric Railway and Light Co., before the Technical League of the Employees' Mutual Benefit Association, Milwaukee, February 19th, 1920.

The boiler tests were carried out under the direction of the Test Engineer and Superintendent of Power Plant, and verified by Paul W. Thompson, Technical Engineer of Power Plants for the Detroit Edison Company.

This paper, report, and test figures are of special importance in view of the decision to instal pulverised coal plant for the new 200,000 kw. super-power station at Milwaukee after tests carried out at the old station over a period of two years had demonstrated the possibilities of pulverised coal firing.

The chief reason for adopting this system, Mr. Anderson says, is that owing to "the recent heavy increases in price of coal any process which promised greater efficiency found a broad field opened up before it for application to stationary boilers. Previous to this time some work had been done in developing its use in locomotives, but the reasons for its application to stationary boiler furnaces and the small saving that might be effected with coal at a low price did not promise to offset the cost of pulverisation. Such conditions did not encourage the use of fuel in powdered form, therefore, until the higher prices of the last three years forced economy in every direction," and that "with coal and air supplies easily adjustable, perfect fire control is assured, and it becomes at once obvious why coal is burned so efficiently in pulverised form.

"In further explanation of this it is well to consider briefly the indications of efficient combustion applied to the steam boiler. Chief among these is the percentage of carbon dioxide, or CO_2.

" The condition desirable is that with the percentage of CO_2 as high as practicable there should be no CO—a condition obtainable to a greater degree in a pulverised fuel furnace than in any other type.

" The percentage of CO_2 to be maintained in pulverised fuel practice is determined to a great degree by furnace limitations rather than combustion consideration. From 16 to 17 % CO_2 in the flue gases is easily obtainable, but it cannot be maintained in actual operation due to exceedingly high flame temperatures that result and the consequent destruction of the brickwork. The temperature of the furnace, therefore, must be regulated by varying the volume of excess air.

" It is known that the combined efficiency of a boiler and furnace does not decrease when the fuel is poor, which condition does not hold true for the stoker. In the case of the stoker, the dropping off in efficiency is at a more rapid rate than the B.Th.U. value of the fuel would indicate as normal, and so much so, that the point is rapidly reached when proper combustion cannot be maintained.

" Operation of a pulverised fuel fired boiler, equipped with proper instruments, can be varied to take big fluctuations in load over very brief periods of time. A heavy overload can be quickly taken on or dropped off by adjustment of the coal and air feeds, and without any waste of fuel as always occurs under like conditions in stoker practice. No losses occur due to clinkering of coal or cleaning of fires, this condition of operation being entirely eliminated.

" Irregularities caused by change in quality and variation in size of coal, such as the fireman cannot successfully cope with on stokers, are also eliminated. Furnace conditions necessary to most economical combustion are more perfectly obtained, and henee a horizontal combined effieiency curve is possible of approximate attainment.

" Due to its easily regulated coal and air supply and its perfectly controlled rate of combustion, the pulverised fuel furnace practically eliminates losses of combustible in ash. Ordinarily this loss is relatively large, and varies according to the nature of the coal, type of stoker and the boiler load carried. In pulverised fuel practice the loss is very small and these variations do not occur.

" The ease with which the fuel feed and draft is controlled, the ability to take on and drop off heavy overloads in a brief time, the thorough combustion of the coal, and the uniformly high efficiency obtainable under normal operation, constitute the chief advantages of pulverised fuel over other methods of coal burning.

" An additional economy is effected during banked boiler hours. Banking conditions when operating with pulverised fuel are somewhat different from those obtained in stoker practice. By stopping the fuel and closing up all dampers and auxiliary air inlets, a boiler fitted for use of pulverised fuel can be held up to pressure for several hours. The furnace brickwork, having been heated to incandescence during operation, gives off a radiant heat which is almost all absorbed by the boiler rather than escaping up the stack intermixed with an excess of cooling air. Radiation losses only occur as against radiation plus stack and grate losses in the case of the stoker.

"Commenting for a moment on the maintenance features of such a plant as has been described, it is the writer's (Mr. Anderson) belief, based on two years' operating experience, that the furnace brickwork in a pulverised fuel furnace will stand up equally as well as a stoker installation, with a very great advantage in favour of the former, due to the elimination of all iron work in the furnace or anywhere near the high temperature zones of the boiler furnaces.

"The object of tests carried out was to obtain complete data on the pulverised fuel installation for the purpose of making comparison with stoker installation, no attempt being made to establish boiler-room conditions other than those maintained during regular operation.

"The coal used, with the exception of the first day, when 100 % Youghiogheny fuel was selected for the test, was a mixture 50 % each Eastern Kentucky and Youghiogheny screenings, running approximately 25 % nut, 45 % pea, and 30 % slack. This coal is the same as is used in daily operation. The coal as supplied to the dryer after passing through disintegrator was approximately 50 % slack and 50 % small pea and nut, not any of the pieces being larger than ½ inch.

"In the pulverised coal storage bins it was found that, during the first twenty-four hours of the test, moisture with its attendant difficulties was collecting in storage bins. Cold air draughts through windows alongside of the bins caused this condition by rapidly condensing the vapour in the entrained air. When the windows were tightly closed it was eliminated."

Test Data. November 11th–15th, 1919.

1.	*Number and kind of boilers*	Five Edge Moor water-tube boilers
3.	Volume of combustion space, cu. ft., per boiler	1678
4.	Water heating surface, sq. ft., per boiler	4680
5.	Superheating surface, sq. ft., per boiler (approximate)	594
	(*a*) Type of superheater	Foster
6.	Total heating surface, sq. ft., per boiler	5274
8.	*Duration, hours*	99
9.	Kind and size of coal	Mixture, 50 % Yough. Scrgs. 50 % Eastern Kentucky Scrgs.
10.	Steam pressure by gauge, lb. per sq. in.	167·8
12.	Temperature of steam leaving superheaters, ° F.	441·9
13.	Temperatures of feed water entering boiler, ° F.	156·3
14.	Temperature of escaping gases, ° F.	496·6
15.	Draft under damper, inches of water	0·173
16.	Draft in furnaces, inches of water	0·031
17.	Air pressure at blower, inches of water	6·36
18.	*State of weather*	
	(*b*) Relative humidity, %	0·72

20 Total weight of coal, as received, lb.	958,074
21. Pereentage of moisture	7·23
22. Total weight of coal, as fired, lb.	894,800
23. Percentage of moisture	0·67
24. Total weight of dry coal, lb.	888,805
25. *Slag, ash and refuse* (dry Laboratory basis), %	11·90
(*a*) Withdrawn from furnace bottom, lb. total	9,770
(*b*) Withdrawn from tubes, flues and combustion chamber, lb. total	9,862
(*c*) Blown away with gases, lb. (difference between Laboratory and actual weighed)	87,549
(*d*) *Percentage of total lost with gases*	82·8
(*e*) Percentage of combustible in slag and ash recovered, % (combined analysis)	6·9
26. Total combustible burned, lb.	781,622
27. Total weight of water fed to boilers	8,249,536
28. Factor of evaporation	1·1473
29. Total equivalent evaporation from and at 212° F., lb.	9,464,693
32. Equivalent evaporation per hour per boiler from and at 212° F., lb.	19,121
33. Equivalent evaporation per hour from and at 212° F., per sq. ft. of water heating surface, lb.	4·09
36. *Percentage of rated capacity developed*	118·4
37. Water fed per lb. of coal, as received, lb.	8·611
38. Water fed per lb. of coal, as fired, lb.	9·219
39. Water evaporated per lb. of coal dry, lb.	9·282
40. Water evaporated per lb. of combustible, lb.	10·554
41. Equivalent evaporation from and at 212° F., per lb. of coal as received, lb.	9·879
42. *Equivalent evaporation from and at 212° F., per lb. of coal as fired, lb.*	10·577
43. Equivalent evaporation from and at 212° F., per lb. of coal dry, lb.	10·649
44. Equivalent evaporation from and at 212° F., per lb. of combustible, lb.	12·109
45. Calorific value of 1 lb. of dry coal by calorimeter, B.Th.U.	12,810
46. *Gross efficiency of boiler and furnace, %*	80·67
47. Efficiency of furnace, %	99·79
49. Carbon dioxide, % in flue gases	12·26
50. Oxygen, %	6·82
51. Carbon monoxide, %	0·00

52. *Proximate analysis of coal :—*

	As Received.	As Fired.	Dry.
(*a*) Moisture	7·23	0·67	—
(*b*) Volatile	32·13	34·40	34·63
(*c*) Fixed Carbon	49·60	53·11	53·47
(*d*) Ash	11·04	11·82	11·90
	100·00	100·00	100·00

HEAT BALANCE.

—	Method.			
	A.S.M.E.		Uehling.	
	B.Th.U.	%.	B.Th.U.	%.
(*a*) Heat absorbed by the boiler . .	10,334	80·67	10,334	80·67
(*b*) Loss due to evaporation of moisture in coal	8	·06	8	·06
(*c*) Loss due to heat carried away by steam formed by the burning of hydrogen .	486	3·79	463	3·61
(*d*) Loss due to heat carried away in dry flue gases	1,527	11·93	1,551	12·11
(*e*) Loss due to carbon monoxide . .	0	·00	0	·00
(*f*) Loss due to combustible in ash . .	23	·18	23	·18
(*g*) Loss due to heating moisture in air .	39	·30	39	·30
(*h*) *Loss due to combustible carried away* with flue gases, unconsumed hydrogen, hydrocarbons, radiation and unaccounted for	393	3·07	393	*3·07*
(*i*) Total calorific value of 1 lb. of dry coal	12,810	—	12,810	—
(*j*) Total %	—	100·00	—	100·00

TEST ON FUEL PULVERISING EQUIPMENT ONEIDA STREET POWER PLANT.

November 11th–15th, 1919.

General Conditions—Average Temperatures, etc.

1. Temperature of air entering dryer furnace, ° F.			93·8
2. Temperature of gases leaving dryer, ° F.			181·8
3. Humidity of outside air, %			72·0
4. Draft through dryer, inches of water			0·77
	No. 1	No. 2	avg.
5. Vacuum in pulverisers, inches of water . .	5·0	5·16	5·08

Coal Temperatures, Moistures and Fineness.

6. Temperature of coal entering dryer, ° F.	88·2
7. Temperature of coal leaving dryer, ° F.	237·9
8. Temperature of coal leaving pulverisers, ° F.	169·7
9. Moisture of coal entering dryer, %	5·59
10. Moisture of coal leaving dryer, %	1·61
11. Moisture of coal leaving pulverisers, %	1·03
12. Fineness of pulverised coal, 200 mesh, %	81·30
13. Fineness of pulverised coal, 100 mesh, %	97·40
14. Fineness of pulverised coal, 80 mesh, %	99·30
15. Fineness of pulverised coal, 60 mesh, %	100·00

Total and Hourly Quantities.

Crusher.

16.	Total coal crushed, as received at crusher, tons	479·0
17.	Coal crushed per hour, as received, tons	17·5

Dryer.

18.	Total coal dried, as received at dryer, tons	471·2
19.	Total coal dried per hour of dryer operation, as received, tons	6·7

Pulveriser.

20.	Total coal pulverised, coal from dryer, tons	447·4
21.	Capacity of pulveriser per hour, tons	5·0
22.	Coal pulverised per hour, dry, tons, total	7·90
23.	Coal pulverised per hour, dry, tons, per mill	3·95
24.	Coal pulverised per hour, per mill, as received at plant, tons	4·23

Consumption of Lubricants.

24*a*.	Total grease consumed by elevators and conveyors, lb.	6·0
25.	Grease per ton of coal, as received, lb.	0·012
26.	Total grease consumed by pulverisers, lb.	13·0
27.	Grease consumed per pulveriser per hour of operation, lb.	0·112
28.	Grease consumed per pulveriser per ton of coal pulverised, lb.	0·028
29.	Grease consumed on all equipment per ton of coal, as received, lb.	0·040
30.	Total oil consumed on all equipment, quarts	17·0
31.	Oil consumed per ton of coal, as received, quarts	0·036

Electric Energy and Coal Consumption.

32.	Total energy consumed by crusher and green coal elevator		220·0
33.	Energy per ton of coal, as received, kw. hrs.		0·47
34.	Total energy consumed by dryer, kw. hrs.		735
35.	Energy per ton of coal, as received, consumed by dryer		1·53
36.	Total energy consumed by pulverisers, kw. hrs. (Fan and drive motor)		8,010
		Mill No. 1	Mill No. 2
37.	Motor input per hour, h.p.	93·8	90·2
38.	*Energy consumed by pulveriser per ton of coal, as received, kw. hrs.*		16·72
39.	Energy consumed by pulveriser per ton of coal, as pulverised, kw. hrs.		17·90
40.	Total energy consumed by pulverised coal conveyors, feeder blowers and feeders, kw. hrs.		1,789
41.	*Total energy consumed by pulverised coal conveyors, feeder blowers and feeders per ton of coal, as received, kw. hrs.*		3·73

42. Total energy consumed by pulverised coal conveyors, feeder blowers and feeders per ton of coal, as fired, kw. hrs.	4·00
43. Total energy consumed by all equipment on preparation and firing of pulverised fuel, kw. hrs.	10,754
44. *Energy per ton of coal, as received, kw. hrs.—Grand Total*	22·45
45. Coal equivalent for this energy at 1·5 lb. coal per kw. hr., lb.	33·68
46. Total coal used in dryer furnace	12,291
47. Coal per ton of fuel dried, lb. (based on coal as received)	25·66
48. Total coal and equivalent consumed in preparation and firing of one ton pulverised fuel, lb.	59·34

Cost of Preparation—Operation and Maintenance.

49. Cost of labour per ton of coal—operation	$0·143
50. Cost of fuel for drying, plus fuel for electric energy—Coal at $4·00 per ton	0·119
51. Cost of lubricants per ton of coal—Grease at 9c. per lb.	0·007
52. Cost of labour per ton of coal—Maintenance	0·036
53. Cost of material—Maintenance	0·020
54. *Total cost per ton of coal*	*$0·325*

Note.—Item 49 is based on the labour required to pulverise coal sufficient for five boilers through a 24-hour run per day.

SUMMARY SHEET.

1. Energy consumed by conveyors, crushers, elevators, dryer, blowers and feeders, kw. hr.	5·73
2. Energy consumed by pulveriser, kw. hr.	16·72
3. Total energy, kw. hr.	22·45
4. Coal equivalent at 1·5 lb. per kw. hr., lb.	33·68
5. Coal consumed in dryer furnace, lb. per ton of fuel dried	25·66
6. Total coal and equivalent, lb.	59·34
7. *Gross efficiency less deductions for total coal and equivalent—Item 6*	78·36
8. Labour—Coal preparation	$·143
9. Labour—Firing	0·112
10. Labour—Ash removal	0·025
11. Dryer fuel—Coal at $4·00 per ton	0·051
12. Electric energy—Coal per kw. hr. at 1·5 lb.	0·068
13. Maintenance (Labour at 3·6 c.—Material at 20 c. manufacturer's estimate—Lubricants at 0·7 c.)	0·063

14. Total cost of fuel preparation, firing, ash disposal, and maintenance	0·462
15. Price of coal as purchased, per ton	4·000
16. Total cost	$4·462
17. *Actual gross efficiency, %*	*80·67*
18. *Net efficiency after all incidental costs have been accounted for, %*	*72·32*

Conclusions

Operating Costs for Pulverised Coal Plant and Mechanical Stokers (per ton (2000 lb.) of coal handled).

	Pulv. Fuel System.	Modern Stoker Plant.
		Stokers and blowers, kw. hrs.
Energy consumed to conveyors, crusher, elevators, dryers, fans, and feeders, kw. hrs.	5·73	10·94
Energy consumed by pulveriser, kw. hrs.	16·72	—
Total energy, kw. hrs.	22·45	10·94
Coal equivalent at 1·5 lb. per kw. hr., lb.	33·68	16·41
Coal consumed in dryer furnace, lb.	25·66	—
Total coal and equivalent, lb.	59·34	16·41
Labour—Coal preparation	$0·143	—
Labour—Firing	0·112	0·140
Labour—Ash removal (in plant)	0·025	0·064
Dryer fuel—Coal at $4·00 per ton	0·051	0·000
Electric energy—Coal per kw. hr. at 1·5 lb.	0·068	0·033
Maintenance, Labour, Material, and Lubricants	0·063	0·097
Total cost of fuel preparation, firing, ash disposal, and maintenance	0·462	0·334
Price of coal, as purchased per ton	4·000	4·000
Total cost, per ton	$4·462	$4·334
Cost per ton of coal in P.F. System over modern stoker	0·128	—
Actual gross efficiency, %	80·67	76·80
Net efficiency after all incidental costs have been accounted for, %	*72·32*	*70·88*
Difference in favour of pulverised fuel system, %	*1·44*	—

EXCERPTS FROM FINAL NOTES

By Mr. Paul W. Thompson, on the Pulverised Fuel Application at the Oneida Street Plant

" In order to determine the feasibility of burning pulverised fuel, the Milwaukee Electric Railway and Light Co., early in 1918, decided upon a trial installation on one of the 468 h. p. boilers in the Oneida Street Power Plant.

" It is unnecessary to go into the details of the test or methods employed, as these will be found in the final report of the test. It is sufficient to say that the test was properly conducted and particular care exercised in obtaining an accurate record of all quantities involved.

" Losses which are inherent in stoker practice, such as breakdowns in the stoker itself, breaking up clinkers, loosening clinkers, continually watching the fire to maintain correct and uniform thickness, watching the gas passes of the boiler to see that no large sparks which indicate a carrying away of combustible, dumping, and the many other operations that are necessary in stoker operation, are eliminated. In other words, efficient combustion is obtained at all times without continual supervision by an experienced operator, and from the standpoint of reliability of operation the odds are in favour of the pulverised fuel. This is an item for serious consideration in plants designed with 4·5 kw. capacity or more per installed boiler h.p., where the losing of a boiler due to stoker trouble at the time of maximum load on the station might seriously overload the remaining boilers or make it necessary to drop a portion of the load on the plant.

" A large portion of the ash resulting from combustion is carried on through the passes of the boiler and out of the stack. Owing to the fineness of this ash it apparently carried a considerable distance, even in a moderate wind before being precipitated.

" Strictly speaking, there is no such thing as a banked boiler when using pulverised fuel, as all that is necessary when it is desired to cut out a boiler is to shut off the coal feed and close all the dampers and auxiliary air inlets to the furnace. In this way the Milwaukee Electric Railway and Light Co. have found by test that it is possible to hold the boiler up to pressure for about ten hours by the radiant heat stored up in the furnace and boiler setting which is gradually absorbed by the boiler.

" In a plant where the ratio of boiler hours to boiler steaming hours averages 43 % or greater, which corresponds to an average daily plant load factor of 67 %, the saving resulting from the use of pulverised fuel is worth considering. Assuming 0·2 lb. coal consumed per B.h.p. banking hour in a plant equipped with underfed stokers, this loss amounts to about 1·5 %, which in a pulverised-fuel burning plant should easily be reduced to one-half this figure, resulting in a net saving of 0·7 % on this one item alone.

" The writer (Mr. Thompson) does not believe that under test conditions over a period of constant boiler rating the efficiency obtained with the use of pulverised fuel will exceed that which has been obtained from the best stoker practice under

similar operating condition. However, under normal operation it is believed that the elimination of the many variable conditions entering into stoker operation will result in higher efficiency for the pulverised fuel installation. Overall efficiencies

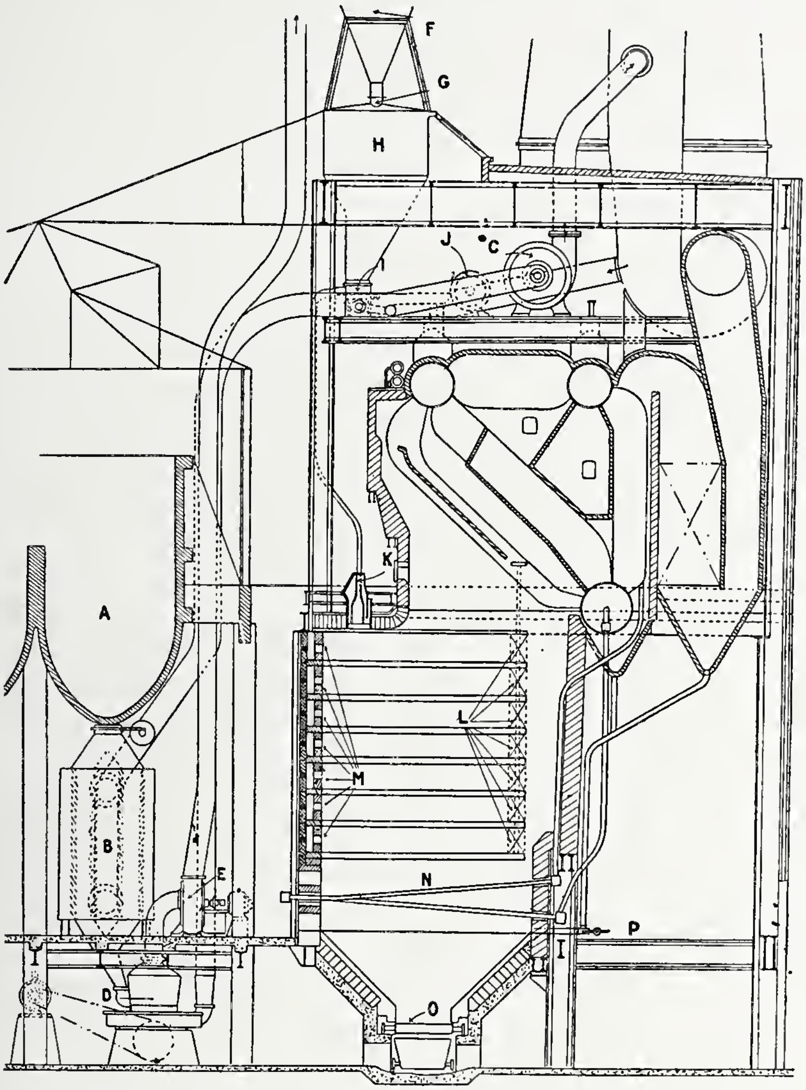


FIG. 159.—Sectional Arrangement of Lopulco Boiler Equipment and Usco Static Coal Dryer at Union d'Electricité Central Power Station, Paris.

A Raw coal bunker. *B* Usco static coal dryer. *C* fan for supply of waste heat (flue gases) to dryer. *D* air separator Raymond pulveriser mill. *E* fuel separator fan. *F* base of cyclone fuel separator. *G* screw conveyor. *H* fuel bunker. *I* feeder mixers. *J* motor fans for feeder mixers. *K* vertical burners. *L* secondary air inlet ports to air heating channels. *M* secondary air ports from hot air cavity to combustion chamber. *N* feed water tube screen to prevent fusion of ash. *O* ash removal door. *P* steam ejector for removal of ash dust from boiler and economiser tubes.

of boiler, furnace, and grate as high as 82 or 83 % have been obtained on test with stoker-fired boilers, but normal operation day in and day out seldom exceed 76 % in the very best practice where highly skilled help is employed in supervising the boiler-room operation."

The decision arrived at, following upon these investigations, has been one of

the greatest moment in the history of pulverised coal as a boiler-house fuel. The credit of successful development of pulverised fuel in the future operation of steam-driven power units must be given to J. Anderson, for to his courage in standing by his firm convictions the whole future of pulverised fuel firing for super power house work is directly attributable. An immediate sequence to this first comprehensive scheme has been the decision made by the engineers of the Union Electric Co. to equip the new 240,000 kw. power station at St. Louis with boilers fired with pulverised coal on the same principle as that adopted at Milwaukee. The Detroit Edison Marysville Station to house boilers each of 29,800 sq. ft. heating surface; the Cleveland Electricity Co., at whose station boilers each of 30,500 sq. ft. heating surface are to be erected; and, possibly, the Detroit Edison Trenton Channel Station will be arranged for pulverised coal firing.

The installations referred to above indicate the progress made, and being made, in the U.S.A., and the result of this progress is now being reflected in Europe. In France the super power station at Vitry, for l'Union d'Electricité of Paris, is being equipped with pulverised fuel fired boilers each to evaporate 185,000 lb. of water per hour.

A sectional view of boiler installation, showing the static Usco Coal Dryer as now used for these large power plants, is shown in Fig 159.

The 2600 H.P. Boilers at River Rouge.

One of the most interesting, and at the same time one of the most important, pulverised coal-fired boiler plants in America, which has been in operation for some considerable time, is that at the Ford Works at River Rouge. The information given below has been taken from *Power*, November 1st, 1921.

At these works, at the time of writing, are the largest single units in operation in the world, each boiler containing 26,470 sq. ft. of steam-raising surface. The final plant is to contain eight of these boilers, four on either side of the boiler-room. Actual tests have been taken on the boilers when steaming at the rate of 360,000 lb. per hour when fired only with pulverised coal.

American rating of boilers is taken at 10 sq. ft. of heating surface and $34\frac{1}{2}$ lb. of water evaporated per boiler h.p. On this basis the usual area provided for combustion chambers for boilers is approximately equal to 2 cu. ft. per boiler h.p. for fuel of say 14,500 B.Th.U. per lb. The lower the calorific value of the fuel, the greater the quantity to be consumed for any given boiler duty, and, in consequence, additional combustion, or rather ash accumulation area, must be allowed for.

Owing to the arrangement of the boiler heating surfaces, and to the provision of a combustion chamber having sufficient volume for the simultaneous burning of blast-furnace gas and pulverised coal, the overall height of the boiler unit and furnace is very considerable, being about 85 ft. Between column centres, each boiler measures in plan 29×31 ft., making a floor space equivalent to 0·034 sq. ft. per sq. ft. of steam-raising surface.

Fig. 160 shows one of these double-ended 2640 h.p. boilers with upper and lower drum on each side.

By means of four gas burners on either side, blast-furnace gas was originally fed

horizontally into the furnace near the bottom. For powdered coal there are twelve feeders and four triplex burners of the Lopulco type, two on either side of the boiler, the latter being located in a recess under the lower boiler drum and feeding down into the furnace close to the front wall. To prevent overheating of the front walls, and to provide a flexible arrangement for the admission of air in sufficient quantities and at the location desired, numerous small doors or dampers have been provided in the furnace fronts.

At the bottom of the furnace is a large ashpit divided into four hoppers, each of which is fitted with a 3 × 4 ft. ash gate operated by an air piston. In the arched bottom of the ashpit inspection doors are provided, and also end doors in the side walls. Besides permitting of inspection, these doors provide openings though which the slag may be loosened in case of necessity.

It was originally intended to fire these boilers with blast-furnace gas and pulverised coal, the latter to be used to meet steaming requirements when the supply of gas was inadequate. Since the starting up of the plant, for a time, certain boilers were run entirely on pulverised coal, the available supply of blast-furnace gas being burned separately under one or two boilers. It was found, however, that the use of blast-furnace gas in conjunction with pulverised coal firing is beneficial in maintaining the ash in solid formation, for the heavy particles of ash descend through the relatively low-temperature blast-furnace gas flame and remain unfused, so that the ash deposit in the combustion chambers of these boilers is easily removed. For this reason, it is understood that blast-furnace gas and pulverised fuel are now used together whenever possible.

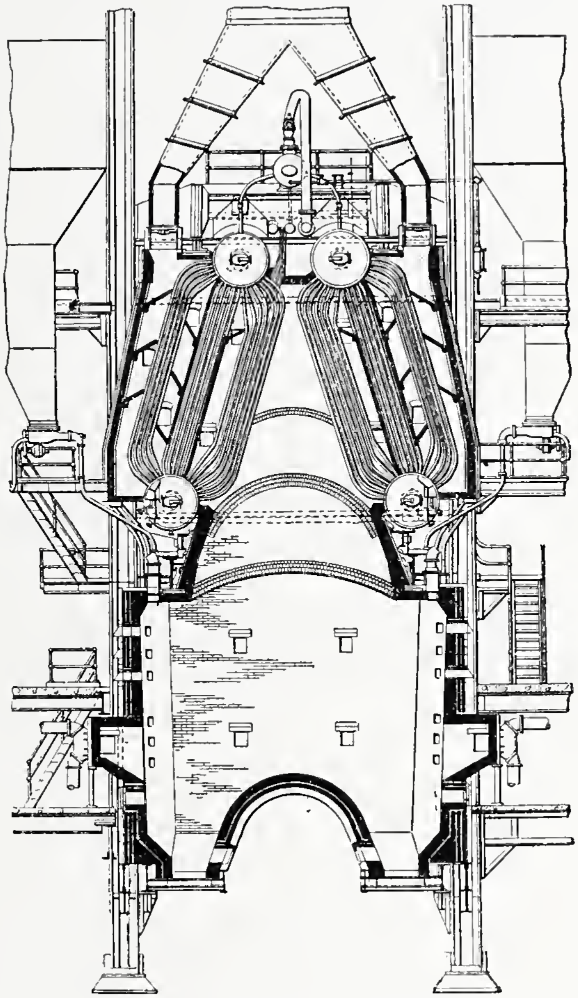


Fig. 160.—Sectional view of 2600 h.p. boiler at the Ford Company's River Rouge Works for Pulverised Coal and Blast Furnace Gas Firing. (*Lopulco System.*)

On the pulverised coal-fired boilers at River Rouge, normal operation at double and treble actual maker's rating of boilers is usual, and peak loads up to four times maker's rating have been maintained. The gas available ranges from 90 to 100 B.Th.U. per cu. ft. On a basis of 70 % efficiency the amount of gas available is only sufficient to develop continuously about 80 % of the nominal rating on each boiler, so that the greater part of the load is carried by the powdered coal-fired units.

For full operation 1000 tons of coal is required per day. The coal is crushed

into $1\frac{1}{2}$-in. cubes and is carried by belt conveyor to a 90-ton hopper in the pulveriser house. From this hopper it is distributed into an overhead bunker of approximately 700 tons capacity for supplying 12 six-roll low-side Raymond mills, each having a capacity of 6 tons per hour. The pulverised coal is finally delivered on to either one of two 16-in. screw conveyors leading across a bridge to the boiler house, and by means of subsidiary conveyors the fuel is supplied to individual bunkers serving each boiler. The bunkers are made of steel plate lined with concrete. Those at either side have a capacity of 200 tons each and those over the central aisle hold 350 tons.

The Lopulco feeders are motor-operated, and are controlled by means of rheostats on a special control board provided for each boiler. With both field and armature control, these motors have a speed variation of three to one. The controlling mechanism is so arranged that the speed of each feeder may be varied at will or all feeders in use on one boiler may be varied in unison by a master controller. The revolutions of the feeders are recorded by solenoid operated counters on the control board, and as the screw feeders are calibrated for the particular coal used, the weight of the coal fed to each boiler is obtained.

Limitations of Mechanical Stokers.

The fitting of forced draught and mechanical stokers to secure higher rates of coal consumption for given flue diameters has been the only means of increasing the steaming capacities of internal fire-tube boilers, with, however, little improvement, if any, in boiler efficiency. With mechanical stokers of the most approved type the efficiency of say a Lancashire type of boiler will seldom exceed 60 % under average working conditions, unless special low-ash coal of non-caking quality and of high calorific value is used. With hand-fired boilers efficiency falls to, say, 54 %, and only then is this figure maintained with suitable good-quality coal.

Mechanical firing obviates some of the many defects mentioned in the chapter on "Combustion," and to a greater extent in the water-tube type of boiler than in the shell type. With stokers, the fire bed is maintained at a more or less even thickness, and the air supply can be kept under better control. Conditions, however, vary considerably with different types of mechanical stokers and boilers. In the Lancashire type, the grate is not wide enough to allow side automatic cleaning, which, if done, reduces the effectiveness of the stoker at cleaning periods to the level of a hand-fired grate, whilst stokers which discharge clinker at the end usually mean a heavy bill for burnt-out fire-bar ends and replacement of warped bars.

With both hand and mechanical firing there is a constant loss due to small coal dropping through the bars, or the discharge of unburnt fuel with the clinker. Water-tube boiler stokers deteriorate very rapidly under banked fires and at forced rating, so much so that there is danger of the bars or links becoming so weak that an absolute collapse may occur. Should this take place, or should the driving mechanism fail under stress of peak load conditions, the stoker and its boiler are put out of commission. The same might be said of pulverised coal boiler equipment, but the argument does not hold good. Pulverised coal burner apparatus is light, is driven by small motors, and is designed to operate at high peak loads

as normal duty. That the maintenance cost of mechanical stokers is a very considerable item, quite apart from the cost of complete replacements due to the entire collapse of stokers, are facts well known to station engineers.

(Authentic figures as to overall costs for mechanical stoker installations and pulverised coal equipments are given at pp. 198 and 199.)

The width of grates of shell type boilers is confined to flue diameters, and in length seldom exceeds 6 ft., owing to practical operating considerations. The ratio of grate areas to boiler-heating surface varies between 22 and 29 to 1, and for hand-firing the quantity of coal burnt per hour is about 20 lb. to 22 lb. per sq. ft. of grate. On mechanical stokers 26 lb. to 28 lb. of coal per sq. ft. of grate can be burned with economy. The rate of fuel consumption on grates is, therefore, confined to a predetermined maximum. The use of fuel in pulverised form will often render it possible to increase the steaming rate of even shell types of boilers.

Internal Fire Tube Boilers.

External combustion chambers are necessary when applying pulverised fuel to boilers of the Lancashire type, the products of eombustion passing through brick-lined tubes into the boiler flues. Fitted in this manner, heat is transmitted to the water in contact with the whole surface of Lancashire boiler flues, and thus a gain over hand or stoker firing of about 42 sq. ft. of heating surface is made for each 3 ft. 6 in. diameter flue. The temperature of gases entering the flues will be about 2600° F. for pulverised fuel firing as against 1800° F. for hand firing with " nuts " of 10,000 B.Th.U., or as against 2200° F. for mechanical stokers working at their highest point of efficiency.

That the degree of fineness of pulverised fuel has much to do with successful results is indisputable, and given confined combustion areas such as are only possible with Lancashire and boilers of similar types, " fineness " is one of the chief factors controlling the degree of efficiency obtained when fuel is applied in this manner.

A suggested design of combustion ehamber for such boilers is shown in Fig. 161. The area of the firing tubes can be taken in some degree as part of the combustion area, and, allowing for a slight reduction in efficiency as against water-tube boiler practice, the exterior combustion chamber area can be reduced to a minimum of say 20 cu. ft. per lb. of coal per minute; at the same time any increase in area above this figure will ensure better firing conditions and less accumulation of ash in the boiler tubes, or in the side flues of the boiler setting.

The suggestion is made by the author that in conjunction with Lancashire boilers, *i.e.*, shell type boilers fitted with large-diameter internal fire-tubes, a water-jacketed connector tube or tubes as shown in Fig. 162 can be used with some advantage. The effect of this attachment might be to cool the flame temperature and, therefore, the temperature of the fine ash carried in suspension in the gases, due to combustion, and so prevent the formation of an impervious layer of fused ash on the boiler tubes. This arrangement has, however, not yet been put into

operation, and the possible results of using such a water-jacketed connector tube have yet to be determined.

In the case of these internal fire-tube boilers provided with combustion

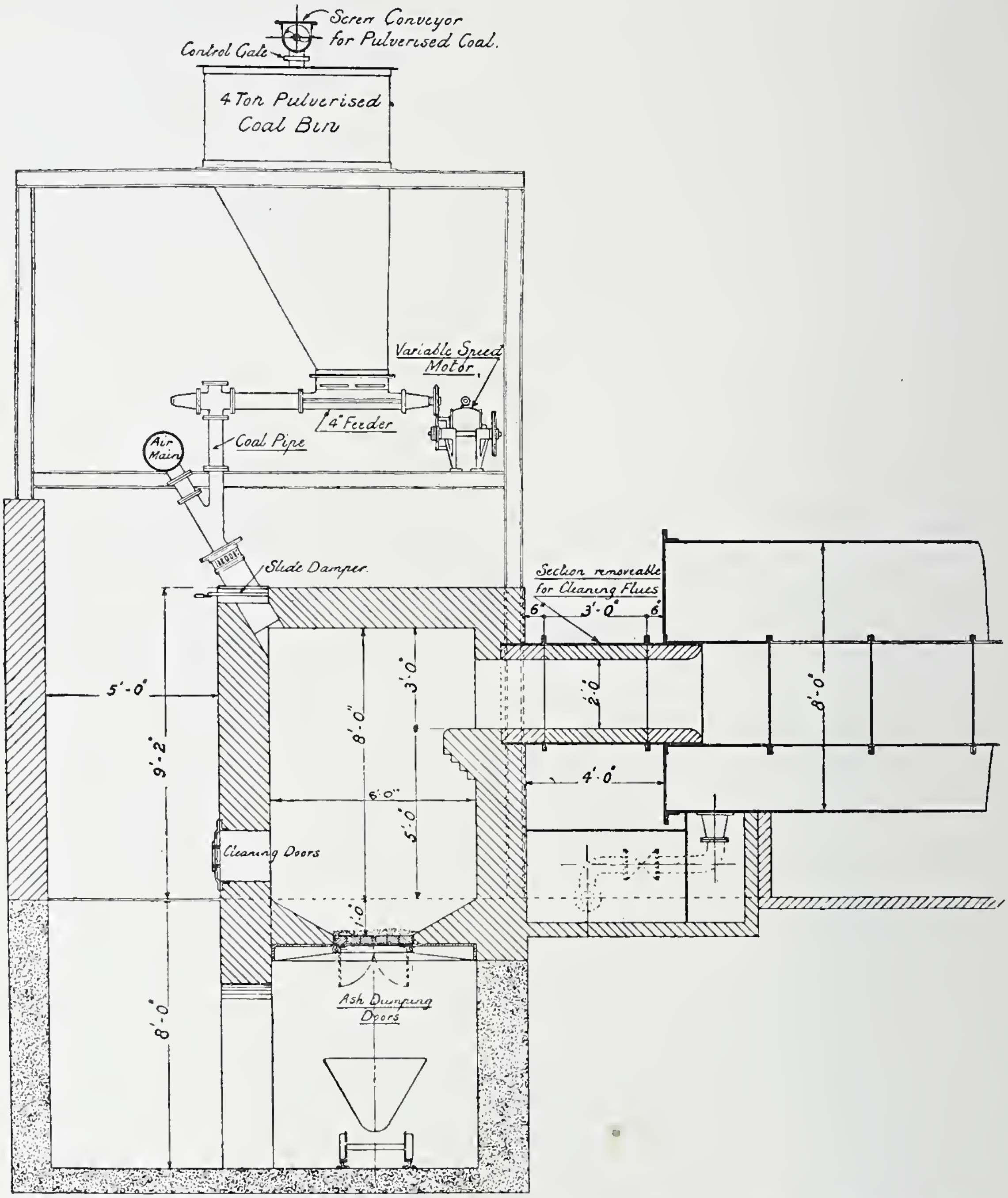


Fig. 161.—Pulverised Coal Fired Internal Fire Tube (Lancashire) Boiler, showing External Combustion Chamber.

chambers below the required minimum area, there will be a fairly heavy deposit of ash, and perhaps slag, in the tubes, and considerable quantities of dust in the flues. Adequate facilities must be provided for clearing away these deposits.

The application of pulverised fuel to internal fire tube boilers, Lancashire, Cornish, Scotch, Marine, and other types, presents a field for experiment and research. Little has been accomplished in this direction. As a rule, these boilers are not found in large numbers in one-boiler installation, but there may be collectively a considerable number at large industrial works in various departments, for which, combined with other fuel requirements, a complete pulverised coal plant could be erected with economy.

Boilers of the Lancashire type are more frequently found as single units or in groups of one to six. For such, pulverised fuel must be obtainable from outside sources, or a self-contained pulveriser unit be designed suitable for the supply of pulverised fuel to each, or to a pair, of boilers.

These are the main reasons why this method of firing has not made greater

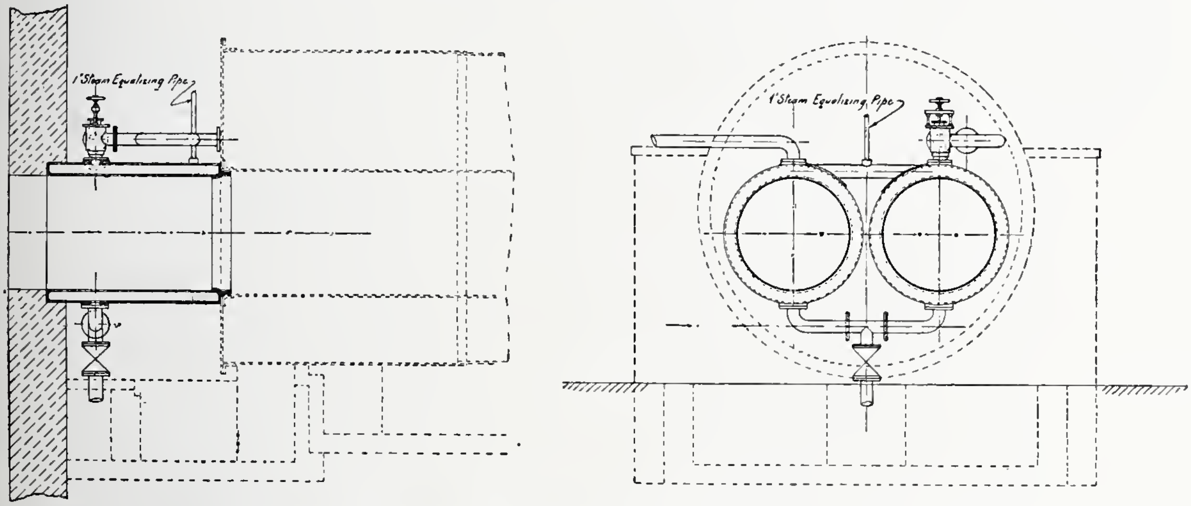


FIG. 162.—Water-jacketed Connector between Combustion Chamber and Fire Tube of Boiler.

headway in connection with internal fire tube boilers. All the practical work has therefore been accomplished with water tube boilers.

Loss of Combustible in Clinker: Wastage while " Banking.

W. G. Wilcox records some actual figures for loss of carbon in ash at a large works in America where mechanical stokers are operated under skilled supervision. Test analyses show the following results :—

			Actual percentage of carbon lost.
Over-feed stokers . . .	26%	Unburned carbon in ash .	4·6
Chain-grate stokers . .	35%	Unburned carbon in ash .	6·1
Hand-firing	35% and upwards	Unburned carbon in ash .	6·5 and over

In gas producer ash from good coal, 20 % unburned carbon is considered good practice, and for poor, dusty coal, 50 % and upwards is often recorded.

Pulverised coal firing can be maintained so that less than 1 % of unburned carbon will remain in the ash.

F. P. Coffin, writing in *Power*, July 12th, 1921, on the subject of coal burned during banking periods at a power station, says :—

"The amount of coal burned during banking periods varies with the service conditions. Many of the central stations that supply large cities have to provide light for numerous office buildings, for which the demand for electric current may be sudden when a thunderstorm occurs and dark clouds interrupt the daylight. This necessitates carrying banked fires in the summer season to nearly the same extent as in the winter. In fact, the highest peak load over the whole year is sometimes caused by summer thunderstorms."

Banked fires are carried at "hot bank" or "cold bank" according to the time available for getting a boiler on the line and under full load. A "hot bank" or "live bank" consists in carrying full steam pressure and having the fire in condition to get the boiler up to normal rating in from five to seven minutes. A "cold bank" or "dead bank" consists in burning only enough fuel to keep up a low steam pressure. On modern underfeed stokers the average coal consumption during banking is about as follows (the "time" is that required to bring the boiler up to normal rating) :—

Fire.	Time in Minutes.	Percentage of Fuel at Full Load.
Live bank	5 to 7	7·5 to 10·0
Dead bank—		
after 24 hours	11 to 15	2·5 to 3·5
after 48 hours	25	

When a fire is run on "dead bank" for a considerable period the accumulation of ash renders it impracticable to start up as rapidly as after a shorter period.

When pulverised fuel is used, steam is held over-night with only a small drop in pressure, and in the morning about four minutes' firing suffices to bring the pressure up to normal. This indicates that it will be necessary only to burn fuel periodically at intervals of several hours, and in small quantities to maintain steam pressure in continuous stand by service comparable with live banking on stokers.

For either hand or mechanical firing of lump coal, there is a constant loss of fuel each time the boiler is put off for cleaning. Take, for example, a pair of chain-grate stokers, each 6 ft. wide (total width 12 ft.) and 12 ft. long, the coal bed being normally 4 in. thick, speed of grate travel 20 ft. per hour, and burning small coal such as "peas." This grade of coal will weigh approximately 5 lb. per sq. ft. per 1 in. deep. The mean thickness of fire would be, say, 3 in., hence 114 sq. ft. by 3 by 5 gives 2160 lb. of coal on the grates during any instant of normal working.

The hourly consumption at 20 ft. travel would be $\frac{3 \times 5 \times 20 \times 12}{144} = 25$ lb. per sq. ft. of grate. In slowing up to, say, half speed the coal burns away, leaving clinker at the stoker ends only, finishing probably with but 8 ft. of the bed incandescent. Over the last half-hour, the temperature in the combustion chamber

falls to 1500° F. or less, the drop in temperature being due entirely to an excess air supply of at least 200 %. The coal consumed under these conditions would be, say, 1000 lb. and the coke lost on the grate would amount to about half this, viz. 500 lb.

Under pulverised coal firing conditions, the temperature in the combustion chamber remains steady until shutting down the boiler, and when this is done, the consumption of fuel ceases immediately.

Combustion Chamber Areas.

A definite figure for combustion area per lb. of pulverised fuel burned per hour has not yet been satisfactorily established.

The usual figure accepted for boiler firing has been about 40 cu. ft. per lb. of coal per minute, or 1·5 lb. coal per minute per cu. ft. of furnace volume, and for locomotives a figure as low as 10 cu. ft. per lb. of coal per minute has to be accepted, for the combustion area is very restricted under these conditions. N. D. Savage in his American Iron and Steel Institute Paper, May, 1921, says :—

" It has been shown, by various tests, that capacity is in direct proportion to furnace volume, and that in the furnace upon which it has been possible so far to make determinations, the most efficient rates of combustion have been at from 1 to 1·5 lb. of coal per minute per cu. ft. of furnace volume, although efficiencies change very little in a properly designed furnace up to 2 lb. per cu. ft., and satisfactory operating results can be secured at from 0·5 lb. per cu. ft., which permits a very wide operating range. At one boiler plant, an efficiency of 78·8 % was obtained when burning fuel at the rate of 1·81 lb. per cu. ft. Assuming a rate of combustion of 1·75 lb. per cu. ft., the Milwaukee Lakeside furnace (Fig. 157), which has a volume of 8000 cu. ft., will burn efficiently 14,000 lb. of coal per hour. Assuming the coal to have 12,500 B.Th.U. and operating at only 77½ % efficiency, this would be equivalent to 4000 h. p. on these 1308 h.p. boilers, or approximately 300 % rating. At 2 lb. per cu. ft. the rating would be practically 350 %."

Recent practice in France at several collieries where boiler plants are now working on pulverised low-grade coal, has established a more generous combustion area if the ash is to be maintained in a dry, dusty formation. It has been found that with reduced combustion area the ash deposited in the chambers will either fuse and solidify into clinker or remain liquid so that it can be run off, according to the size of combustion chamber provided. The smaller the area the more liable is the ash to fuse.

In order to render ash removal as easy as possible, the ash should be prevented from fusing even to the slightest extent. When, therefore, space is available for large combustion chambers, ash can be retained in dry dust formation. J. G. Coutant, during his work in this direction in France, has concluded that 5 cu. ft. per lb. of coal per hour is not only advisable, but essential for satisfactory working with 60 % ash of either high or low fusing point. This combustion area is much greater than is necessary when using a good quality low ash bituminous coal.

For normal water-tube boiler installations, where combustion chambers can be constructed to suit the conditions advocated by pulverised coal engineers, the area of these should be based upon the maximum running load at which the boilers are to be operated. Having found the quantity of coal to be burned for this duty, the combustion chamber area should be not less than 40 cu. ft. per lb. coal per minute. The minimum area permissible for good results with stationary water-tube boilers is perhaps 30 cu. ft. per lb. of fuel per minute for coal containing about 10 % of ash.

The velocity of gases plays a most important part; with high velocities, ash and coal particles are carried in suspension to the boiler tubes, there to build up into the coatings which were so disastrous in early applications. For this reason low pressure air supply from a rotary fan has superseded the original idea of introducing the fuel by means of a compressed air jet. Under present accepted conditions the velocity of gases through the combustion chamber and boiler passes should not exceed 10 ft. per second.

Small Power Stations.

The economy introduced by burning fuel in pulverised form is a matter of degree, and it must not be thought that economy to any useful extent can be effected only for boiler installations of great capacity, such as at the Milwaukee, St. Louis, and other super power stations. It will be shown that for relatively small boiler plants valuable savings can be made in this manner. As an example, take the case of a small electricity supply station.

The following figures have been worked out upon actual data supplied respecting a water-tube boiler plant fitted with mechanical stokers.

Coal consumed 40,000 tons per annum.

Coal per day $= \dfrac{40{,}000}{365} =$, (say) 110 tons coal per day.

Coal now used per kw. hour = 3·5 lb.

$$\frac{110 \times 2240}{3 \cdot 5} = \text{(say) } 70{,}000 \text{ kw. hours per 24 hours.}$$

The above load being distributed through the 24 hours *approximately* as follows :—

8.0 a.m. to 5.0 p.m.	5000 kw.
5.0 a.m. to 9.0 p.m.	2500 ,,
9.0 p.m. to 8.0 a.m.	1500 ,,

The average consumption is 15 lb. per kw. hour.

Hence, total steam required per 24 hours is $70{,}000 \times 15 = 1{,}050{,}000$ lb. of steam.

In order to obtain an idea of the economies to be effected by the use of pulverised coal as against the present method of stoker firing, the following figures are given, relating to actual present loading :—

Calculations for pulverised coal firing can be based on the assumption of an average overall thermal efficiency of the boilers and furnaces of 80%. In practice, efficiencies of 83% to 85% are reached and maintained, but the lower figure is used in this case.

The following conditions have also been provided for :—
Boiler pressure 180 lb. gauge (say 195 lb. absolute).
Superheat 150° F.
Feed water temperature 115° F.
Total steam required at generators = 1,050,000 lb. per 24 hours.

Total heat required for steam at 195 lb. (absolute) =	1198
Less heat of feed water at 115° F.	83
	1115 B.Th.U. per lb.

Heat required to superheat 1 lb. of steam 150° F. at 195 lb. pressure = 84 B.Th.U. (about).

Total heat for 1 lb. of steam at 195 lb. pressure and superheated 150° F. and with feed water at 115° F. = 1115 + 84 = 1199 B.Th.U. per lb.

Assuming 80% efficiency overall of boilers and furnaces the coal required for 120,000 lb. steam per hour at 195 lb. pressure with 150° F. superheat and feed water at 115° F. = 17,130 lb., say, *8 tons per hour* maximum when used in pulverised form.

Heat units required per 24 hours = 1,050,000 × 1199 = 1,259,000,000 B.Th.U.

Assuming coal of 10,500 B.Th.U. per lb.

$$\frac{1{,}259{,}000{,}000}{10{,}500} = 119{,}900 \text{ lb. coal per 24 hours.}$$

Working at 80% efficiency this equals 150,000 lb. coal, or 67 tons per 24 hours.

Present coal per day for stoker firing . .	110 tons	
Estimated pulverised coal consumption. .	67 ,,	
Saving in coal consumed	43 ,,	per 24 hours.

Present cost of coal per 24 hours = 110 tons × 26*s*. per ton = £143.

If the same class of coal be used for pulverising as is at present used for stoker firing it should be sufficient to add a charge of 3*s*. 6*d*. per ton to the cost of raw coal. This charge of 3*s*. 6*d*. per ton allows liberally for all the power and running expenses in the mill house and boiler house, including conveying the coal to the boiler bunkers and the air required at burners, together with 6% interest on capital outlay and 10% depreciation on machinery.

The cost of coal in pulverised form then becomes 29*s*. 6*d*. per ton.

67 tons × 29*s*. 6*d*. per ton = £98 16*s*. 6*d*.

The saving in coal cost is, therefore :—

£143	0	0	
£98	16	6	
£44	3	6	per day.

or £44 3*s*. 6*d*. × 365 = £16,123 *per annum.*

By the substitution of a lower priced coal for the 26*s*. per ton coal used, an even greater saving in money could be effected, and moreover boiler plant in commission can be reduced owing to increased steaming with pulverised fuel.

Self-Contained Units and Water-Jacketed Combustion Chambers.

It is not unusual that metallurgical furnaces fired with pulverised coal are working at a sufficiently high temperature to enable a considerable portion of the ash in the coal to be run off in a molten state.

In the case of steam boilers it is preferable to so arrange the combustion chamber, and to provide certain air inlet ports, that the ash falling in the combustion chamber is kept at a temperature below its fusing point. The ash can then be removed in a convenient loose, dry, powdery or friable form.

This result can be produced only when adequate area of combustion chamber can be allowed. On the other hand, at the Erie City Iron Works, U.S.A., the combustion chamber being smaller than is generally accepted as good practice for pulverised coal firing, a complete jacket of water tubes is built into the walls of the chamber to prevent the fusing of the refractory lining. The feed water entering the boiler is preheated in this nest of water tubes. In such manner the furnace can be worked at a high temperature with only about 5 % excess air supply; the result is that the ash remains in a completely fused condition in the combustion chamber, and is run off through a central tap hole into the ashpit underneath. This is not a recommended method of dealing with ash from fuel burnt under large boilers of land installations, but suggests a means of handling ash in confined combustion chambers, and possibly for marine boilers.

This installation has been in operation for a considerable period, and no difficulty has been experienced in burning fuel in this small chamber, from which the fused ash automatically drains away in the manner described.

At these works two boilers are run on pulverised fuel supplied from self-contained units (see Chapter XVI), one boiler being a 402 h.p. water-tube type, the other a 150 h.p. horizontal return tubular boiler. Overall efficiencies of 75 % are obtained without the use of superheaters, as against 40 % and 50 % efficiency when the boilers were hand fired. The arrangement is shown in Fig. 238.

Without the provision of the water jacket, it would be necessary to run with an excess of air above the normal 25 %; otherwise, the high flame temperature in such close proximity to the refractory lining would destroy the lining.

The area of the combustion chamber shown is equal to about 30 cu. ft. volume per lb. of coal burnt per minute.

This principle of using a small combustion chamber and fusing the ash, if applied to boilers of the more usual stationary types met with in Europe, would often be of very considerable convenience, and would obviate much of the trouble due to discharge of ash dust from the chimney, and the collection of ash on the baffles and in the flues.

It is possible that a modification of this idea could be used in the case of Lancashire boilers, by embedding a network of feed-water heating tubes in the brickwork of the external combustion chamber.

The chief point of interest is that water cooling has been used with apparent success, and this knowledge, and the particulars supplied, may be of use in designing combustion chambers on the same principle, so that pulverised coal firing can be adopted where otherwise it could not be considered.

The Bettington Boiler.

The Bettington boiler, originally designed by Claude Bettington for the purpose of overcoming the various difficulties experienced some fifteen years ago, when the burning of pulverised fuel was first applied to steam boilers, has been very greatly improved in construction.

It is contended, and rightly so, that there is now no need for a special boiler such as the Bettington design, because pulverised coal can be applied with every success to standard water-tube boilers of the Babcock or Stirling types. But it must still be admitted that the new pattern Bettington boiler is undoubtedly one that is likely to receive greater attention in the future.

The boiler being vertical, it can be placed conveniently in a space which might be quite unsuitable for other types of boilers.

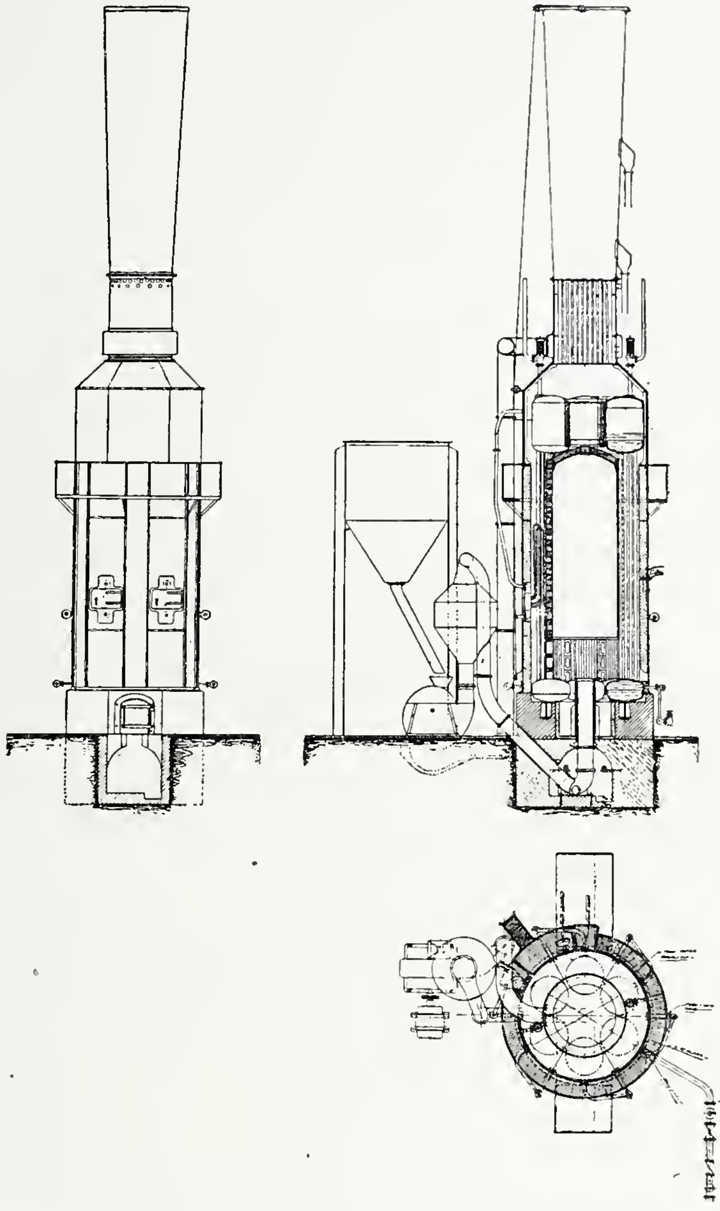


Fig. 163.—Sectional Elevation and General Arrangement of Bettington Boiler and Combustion Chamber. (*Fraser and Chalmers, Ltd.*)

The original design, in which one annular circular steam drum was used, a feature that many critics condemned, has been replaced by a number of smaller separate vertical units, and in this respect the new type of boiler is much in advance of the original design.

The general arrangement of the Bettington boiler, as constructed to-day, is shown in section in Fig. 163, and a single boiler installation in the frontispiece of this book. The boiler consists essentially of a number of main elements arranged symmetrically around the central axis of the boiler. Each of these elements consists

of a top steam drum connected to a bottom mud drum by a number of perfectly straight vertical tubes; all steam drums are connected together by external steam and water circulation pipes, and all the mud drums are similarly interconnected by the feed-water pipes. Superheater units are readily placed between each bank of vertical tubes.

One of the standard sizes of these new type boilers is designed for a normal steaming output of 15,000 lb. per hour, at a working pressure of 500 lb. per sq. in., and every section of a boiler is tested hydraulically at 750 lb. per sq. in. Fig. 164 shows a nest of tubes with top and bottom drums.

The use of straight tubes provides facilities for easy inspection, cleaning, and renewal, and owing to the fact that they are vertical, the deposit of ash and slag on the exterior surface is to a great extent avoided; furthermore, the accumulation of scale inside the tubes is almost entirely prevented. Bettington boilers have operated for several years on hard water without any need for cleaning the tubes internally.

Each unit of the boiler is free to expand and contract without restraint, and without setting up serious initial stresses in any part. This is a matter of considerable importance when working at high pressures.

The combustion efficiency with pulverised coal firing is in the neighbourhood of 98 to 99 %, the ash deposited, see Fig. 165, being of a lightly fused nature, is very easily removed from the ashpit in the base under the boiler. The fine ash dust passing to the stack is collected by an effective arrangement of dust-collector plates fitted in the special chimneys, so formed that the gases are permitted to expand and so to facilitate the extraction of the dust.

On demonstration at full load neither dust nor smoke could be seen leaving the stack, the top of which was only a very short distance above the boiler-house roof. In the boiler house there was no evidence of dust, ashes, or undue heat, and the pulveriser unit made but little noise.

The floor area for a boiler of this type is relatively small. On the other hand, a considerable height is necessary inside the boiler house.

A complete installation, such as the one referred to in the test below and illustrated in the frontispiece, would cost about £5000, including the pulveriser and all necessary pipes, dust and coal separators, stack and fittings.

The following is the record of a test carried out with one of these new boilers.

Bettington Boiler Test.

Duration of test, $5\frac{1}{2}$ hours.
Kind and size of coal, Tamworth Slack.
Number and kind of boiler, 858 Bettington New Type.
Number of sections, 6.
Cubic feet combustion space, 490.
Water-heating surface, 2367 sq. ft.
Superheating surface, 529 sq. ft.
Total heating surface, 2896 sq. ft.
Amount of water contained in boiler to working level, 14,000 lb.

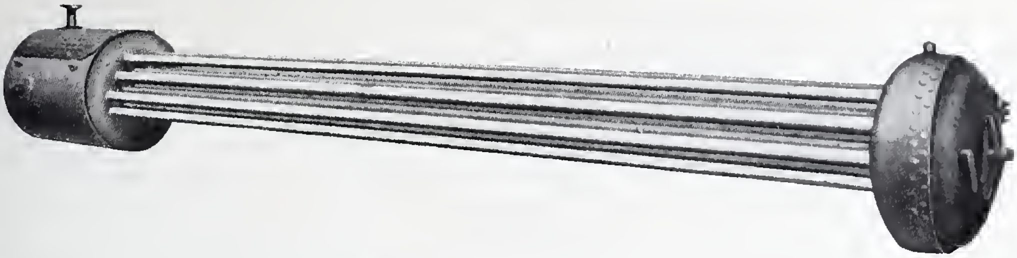


FIG. 164.—ONE COMPLETE SECTION OF BETTINGTON BOILER.

Fraser & Chalmers, Ltd.]　　　　[*The General Electric Co., Ltd.*

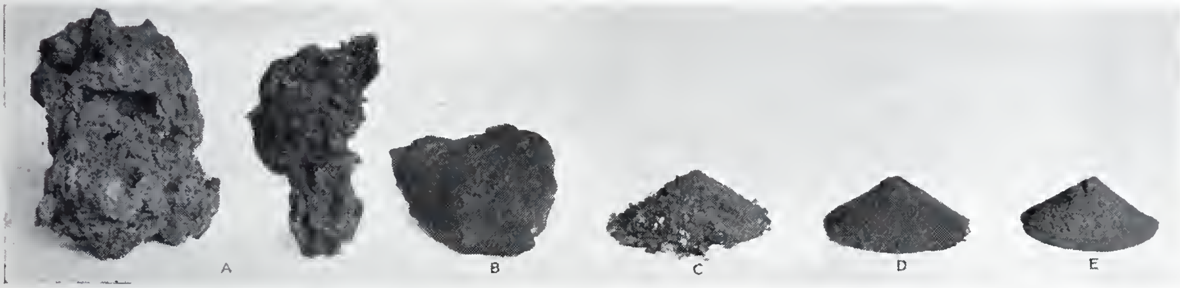


FIG. 165.—EXAMPLES OF CLINKER AND ASH FROM PULVERISED COAL FIRED BOILERS.

A. Light Friable Ash from Bettington Boiler Combustion Chamber.
B. Hard Clinker from O'Brien Boiler Furnace incorrectly fired.
C. Clinker Dust from O'Brien Boiler Furnace correctly fired.
D. Black Dust from Boiler Tubes and Flue obtained with B.
E. Almost White Dust from Boiler Flue obtained with C.

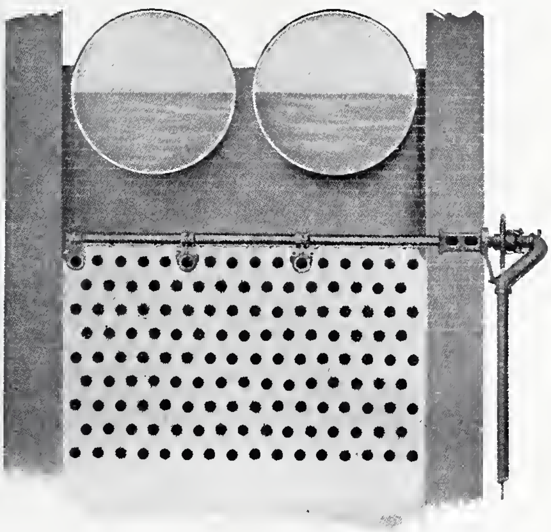


FIG. 166.—DIAMOND REVOLVING UNIT SOOT BLOWER

Babcock & Wilcox, Ltd.]

[*To face p.* 288.

Steam space, cu. ft. 182.
Ratio of water-heating surface to combustion space, 4·83 to 1.
Ratio of total heating surface to combustion space, 5·91 to 1.

Air Heater.

Heating surface in sq. ft., 1010.
Area through tubes, 10·5 sq. ft.
Temperature air entering heaters, 70° F.
Temperature air leaving heater, 380° F.
Total rise in ° F., 310° F.

Average Pressures, Temperatures, etc.

Steam pressure by gauge, 315 lb. per sq. in.
(*a*) Barometric pressure, 29·39 in. of mercury.
Temperature of saturated steam, 427° F.
Temperature of superheated steam, 615° F.
Temperature of gases entering flues, 1300° F.
Temperature of gases under air heater, 840° F.
Temperature of gases after air heater, 600° F.
Temperature of hot air entering pulveriser, 380° F.
Temperature of mixture entering boiler, 200° F.
CO_2 contents at base of flue, 10 %.
CO_2 contents at exit of flue, 10 %.

State of Weather.

Temperature of external air, 57° F.
Relative humidity of air, 30 %.

Total Quantities.

Total weight of coal as fired, 12,096 lb.
Percentage of moisture in coal as fired, 17·84 %.
Total weight of dry coal, 9925 lb.
Ash clinkers and refuse (dry) total 1682 lb.
(*a*) withdrawn from ashpit, 1545 lb.
(*b*) recovered in dust catcher, 137 lb.
Total combustible burned, 8039 lb.
Percentage of ash and refuse based on dry coal, 20·8 %.
Total weight of water fed to boiler, 66,800 lb.
Total water evaporated corrected for quality of steam, 66,800 lb.
Factor of evaporation based on feed temperature, 1·3.
Total equivalent evaporation from and at 212° F., 87,000 lb.

Hourly Quantities and Rates.

Dry coal per hour, 1800 lb.
Dry coal per cu. ft. combustion space, 3·83 lb.
Water evaporated per hour corrected for quality of steam, 12,150 lb.
Equivalent evaporation per hour from and at 212° F., 15,800 lb.

Capacity.

Evaporation per hour from and at 212° F., 15,800 lb.
Rated capacity per hour from and at 212° F., 15,000 lb.
Percentage of rated capacity developed, 105 %.

Economy.

Water fed per lb. of coal as fired, 5·525 lb.
Water evaporated per lb. of dry coal, 6·725 lb.
Equivalent evaporation from and at 212° F. per lb. of coal as fired, 7·2 lb.
Equivalent evaporation from and at 212° F. per lb. of dry coal, 8·77 lb.
Equivalent evaporation from and at 212° F. per lb. combustible, 10·82 lb.

Pulverising.

Speed of pulveriser, 1154 r.p.m.
Size of pulveriser, 48″ × 16″ converted to 48″ × 12″.
Size and speed of motor, 60 B.h.p. @ 1150 r.p.m.
Continuous current.

Motor inputs	volts	250	30·250
	amps.	121	
kw.	watts by meter	32·5	
	efficiency	93 %.	

B.h.p. on pulveriser, 35.
Pressure at pulveriser, $2\frac{7}{8}$ in. of water.

Efficiency.

Calorific value of 1 lb. of dry coal by analysis, 10,546 B.Th.U.
Calorific value of 1 lb. of coal as used, 8,664·3 B.Th.U.
Efficiency of boiler and superheater, 81·1 %.
Efficiency based on coal, 81 %.
Less steam used for driving pulveriser, 2·66 %.
Nett efficiency, 78·44 %.

Cost of Evaporation.

Cost of coal per ton delivered in boiler-room, 18*s.* 8*d.*
Cost of coal required to evaporate 1000 lb. of water from and at 212° F., 14*d.*

Smoke Data.

Percentage of smoke as observed, light grey.

ANALYSIS OF DRY GASES BY VOLUME.

Carbon dioxide	10%
Oxygen	8%
Carbon monoxide	—
Hydrogen and hydrocarbon	—
Nitrogen by difference	82%

APPROXIMATE ANALYSIS OF COAL.

	As fired.	Dry Coal.
Moisture	17·84	—
Volatile	22·73	27·67
Fixed carbon	43·98	53·53
Ash	15·45	18·80
	100 %	100 %

HEAT BALANCE BASED ON DRY COAL.

	B.Th.U.	Dry Coal %.
1. Heat absorbed by the boiler	8,550	81·1
2. Losses due to evaporation of moisture in coal	92	0·88
3. Heat carried away by steam formed by the burning of hydrogen	—	—
4. Loss due to heat carried away in dry flue gases	1,334	12·62
5. Loss due to carbon monoxide	—	—
6. Loss due to combustible in the ashes	—	—
7. Loss due to heating moisture in air; 8. Loss due to unconsumed hydrogen and hydrocarbons, radiation and unaccounted for	570	5·4
9. Total calorific value of 1 lb. of dry coal	10,546	100

Removal of Ash.

This chapter will be concluded with some further reference to the removal of ash from boiler furnaces, from the boiler settings and flues.

It will be seen on reference to established results, as, for instance, to the figures recorded by J. Anderson at p. 269, that between 70 % and 80 % of the total ash content of coal may be ejected at the chimney top. Later results show 10 % to 30 %.

The ash which falls in the combustion chamber may be fused and removed in a semi-liquid form, or, if deposited in solid state, can be raked out and conveyed away by steam jet or suction " pipe " conveyor or removed by tip wagon.

Illustrations of ash and clinker taken from boilers are shown in Fig. 165. A is a lump of ash in dry friable honeycomb formation, as taken from the ashpit of a Bettington boiler; B is a piece of heavy clinker which formed at the bottom of a

combustion chamber of a Heine boiler when this method of firing was first adopted; C shows a small heap of dry, hard ash from the same boiler when firing conditions had been correctly adjusted; D is a sample of dust from the tubes of the Heine boiler when the B clinker was formed. It is of slate colour, indicating 2 % or so of unconsumed carbon; E is a similar sample of dust from the tubes, practically white and with less than ½ % of unconsumed carbon.

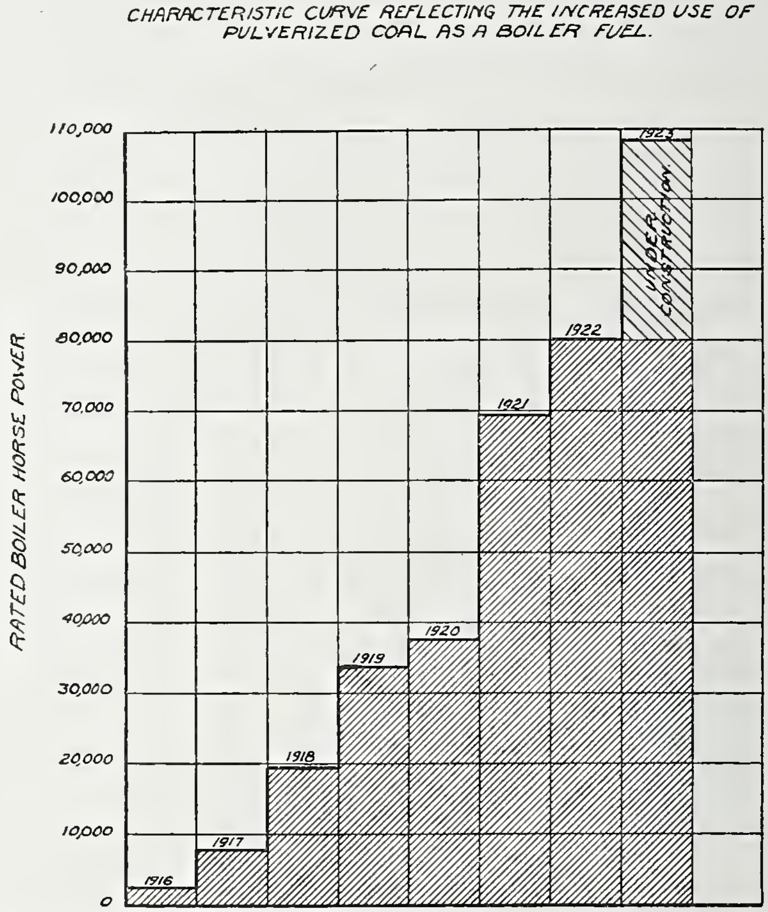


FIG. 167.—Diagram showing Growth of Pulverised Fuel Firing for Steam Raising Plant in the U.S.A. The extension of column for 1923 will be much larger than the shaded portion shown.

The ash in the form of dust which falls below the boiler tubes at each pass is usually removed through a chute to tip wagons provided for the purpose. For a relatively small boiler, where an ash tunnel has not been provided, the accumulation of ash dust below the boiler tubes can be cleared only by hand, or suction, or by mechanical means.

The dust which settles upon the boiler tubes can be readily dislodged by an ordinary portable steam jet. For large plants " Diamond " soot blowers or similar types of effective steam-jet equipment should be permanently installed. A boiler fitted with this apparatus is shown in Fig. 166.

The use of soot blowers has shown very considerable increase in steaming of

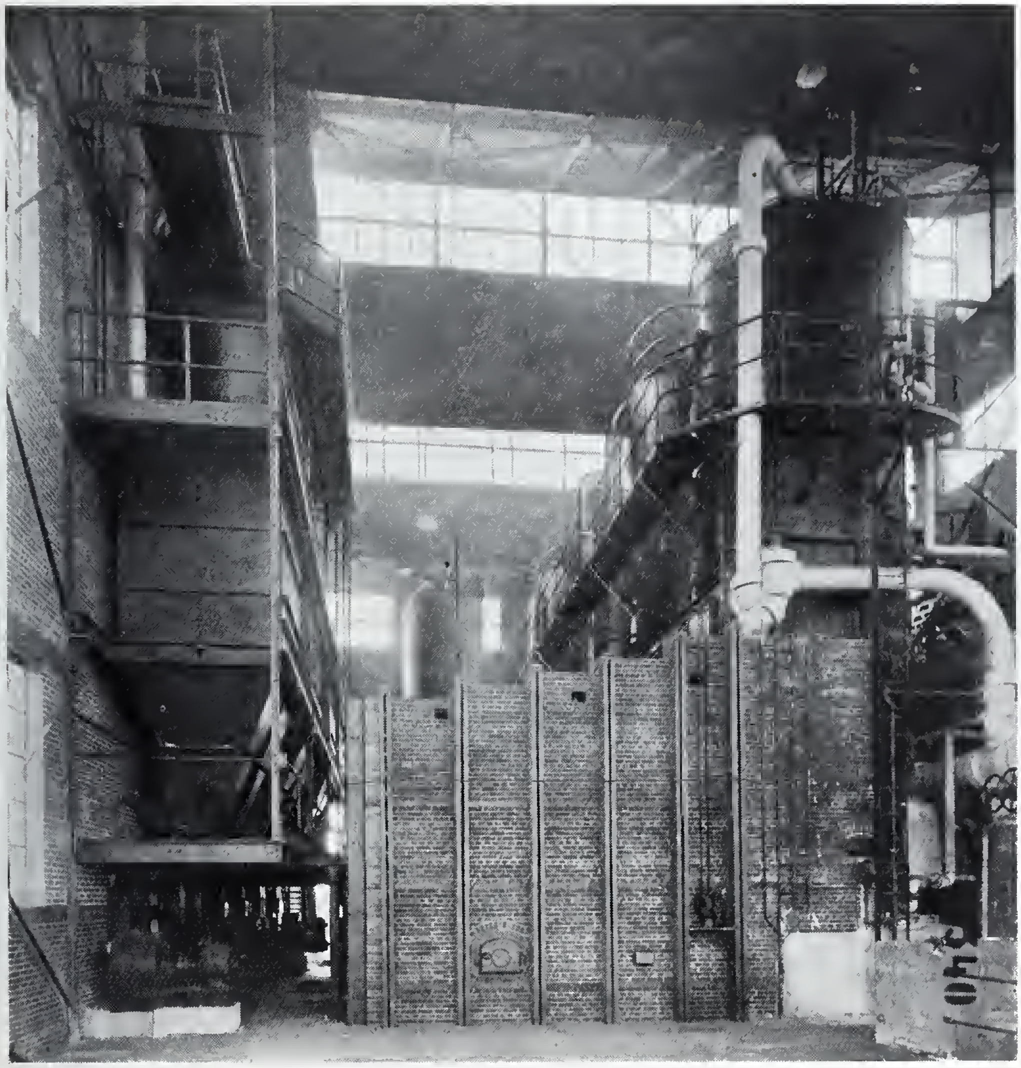


FIG. 168.—FULLER INSTALLATION, SHOWING PULVERISED FUEL BUNKERS AND BURNER EQUIPMENT FOR BATTERY OF WICKES BOILERS.

The Fuller Engineering Co.] [*The Fuller Lehigh Co.*

[*To face p.* 292.

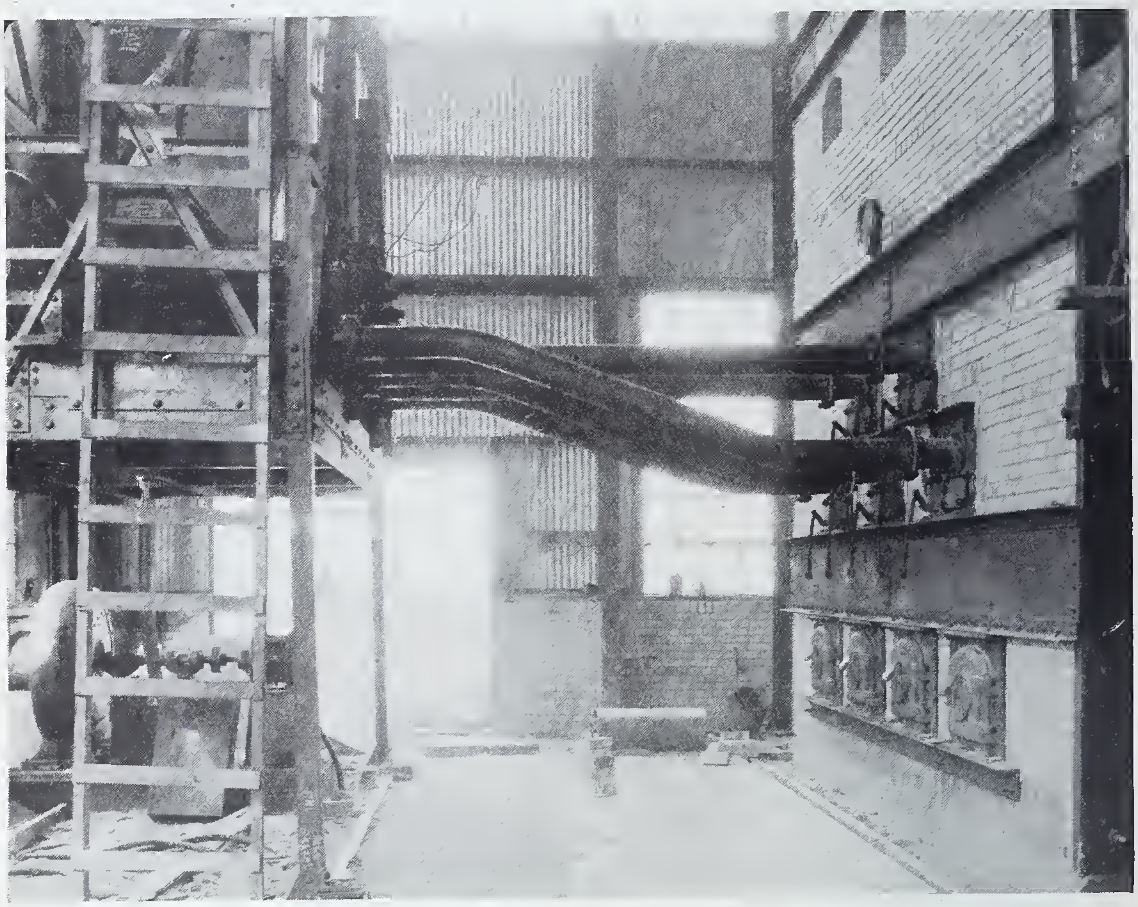


Fig. 169.—Fuller Horizontal Type Burners as fitted to Large Stirling Boiler.

The Fuller Engineering Co.] [*The Fuller Lehigh Co.*

boilers by removal of the black soot deposit formed when coal is burned upon ordinary grates. With pulverised coal firing there is no deposit of either soft soot or hard sludge, but only a ridge of dry, fine dust will collect upon the upper surface of each tube; the remainder of the boiler tube surface will remain at all times perfectly clean and free from any coating.

The growth of pulverised fuel firing for water-tube boilers in the U.S.A. during recent years can be ascertained by reference to Fig. 167. It will be noticed that progress during 1922 was very marked, and, whereas extension to the 1923 column has been made to cover the work in hand at the termination of 1922, the full result of progress made in 1923 will be several times as much as that represented in the shaded portion of the column for that year.

CHAPTER XIV

METALLURGICAL APPLICATIONS

Fuel Economy Records—Fuel used in Iron and Steel Works—Selection of Fuel and Illustrated Applications—Quantity and Fusibility of Ash in Coal—Selection of Refractories—Utilisation of Waste Heat—Blast Furnaces and Reduction of Coke Consumption—Copper-Smelting Reverberatory Furnaces—Open-Hearth Steel Melting Furnaces—Special Burners for Steel-Melting Furnaces—Puddling Furnaces—Sheet and Pair Furnaces—Malleable Iron-Melting Furnaces—Piling and Welding Furnaces—Heavy Forge Furnaces—Light Forge Furnaces—Rivet-Heating Furnaces and Galvanising Kettles—Ore-Roasting and Lime Calcination—Direct Processes for Obtaining Steel from Iron Ore.

When pulverised fuel is employed as a means of heating iron and steel furnaces, the reduction of metal loss or scaling will be appreciable. This is chiefly due to the small amount of excess air present when powdered coal is burned. In one particular instance, 3·68 tons of steel were saved in this manner, per day, on a furnace reheating 168 tons of steel billets. This represents a saving of over 2 % of the weight of metal heated as compared with previous hand-firing practice.

Another special point to be remembered is the economy in labour. The number of men required under hand-firing conditions for the supply of fuel to the furnaces, for firing, and for constant attention to temperatures is usually very much reduced. It can be taken that for the drying, grinding, and transportation of 100 tons of pulverised coal per 10 hour shift, not more than four men will be required, or twelve men for the full working day of 24 hours for 300 tons of fuel. Apart from labour used in the production of pulverised coal, no other men need be employed upon work in connection with the firing of furnaces, for at the furnaces it is often possible to dispense entirely with firemen. When once the furnace is up to temperature, the firing becomes quite automatic, and the men carrying out the actual metallurgical operations can attend to the fuel burners and air supply as readily as for oil or gas firing.

Further, owing to the ease with which a reducing atmosphere can be maintained, oxidation in annealing furnaces is greatly reduced, and the life of annealing boxes is, in consequence, about twice as long as with hand or gas firing.

Fuel Economy Records.

Some actual figures taken from records shown to the author by efficiency engineers at various iron and steel mills in America are given in the following table. These figures show the average saving in fuel consumption that can be made when pulverised fuel is applied to converted furnaces. The class of coal used for the several methods of firing was approximately, if not identically, the same. The fuel consumption figures for pulverised coal refer to the actual fuel used at the furnace, and

do not take into account the additional fuel used in the dryers and mills at the pulverised coal-producing plant.

As will be seen from the computation made for cost of production in terms of coal, p. 193, the addition to be allowed for this is in the neighbourhood of 6 % of the coal used in pulverised form for plants of the average capacity of 100 tons, or so, per 24 hours. An allowance of 10 % of the coal used in pulverised form will be sufficient to cover all purposes.

As against hand firing there is always ample margin in the percentage savings in fuel consumption to cover the equivalent value of fuel and power absorbed in the production, delivery, and burning of the pulverised coal, and still show a considerable saving in fuel, apart from the many other advantages of pulverised coal firing.

Type of Furnace.	Hand Firing.	Pulverised Coal Firing.	Saving Effected.
Annealing Furnaces.			
Malleable iron castings. Coal per ton of castings	880 lb.	340 lb.	61%
Castings annealed per 1 lb. of coal	2·25 lb.	5·8 lb.	—
Cost of annealing pots per ton of castings	$2·25	$0·83	63%
Reheating Furnaces.			
For heavy forge presses. Coal per ton of steel for heating 12 in. steel billets for shells	515 lb.	277 lb.	46%
No. of shells (1060 lb. each) heated	5174 (two furnaces)	4505 (one furnace)	—
Total weight of shells	2449 tons (two furnaces)	2132 tons (one furnace)	—
Coal per ton of steel shells	296 lb.	161 lb.	45%
Medium forge presses. Coal per hour for blooms 102 in. × 18 in. × 15 ft.	650 lb.	350 lb.	46%
Increased output of furnaces 20% when pulverised coal fired.			
For 12 in. rolling mill. Coal per ton of steel	900 lb.	550 lb.	39%
Continuous Reheating Furnace.			
Coal per ton steel billets 5 in. × 7 in. × 14 ft.	220 lb.	168 lb	24%
Open Hearth Steel Melting Furnaces	Producer gas 800 lb.	500 lb.	37%

Fuel used in Iron and Steel Works.

In 1916, the British Association Fuel Economy Committee reported that, from inquiries made at the steel works, the fuel consumption of average bituminous coal for steel melting and casting into ingots was : (1) for 85 % " molten pig process," minimum 6 cwt., maximum 8 cwt., average 6·35 cwt. per ton (2240 lb.) of steel; (2) for 40 % to 70 % molten pig " mixed process," minimum 6·25 cwt., maximum 8·75 cwt., average 7·65 cwt. per ton of steel; (3) for the all " cold process," minimum 7 cwt., maximum 12 cwt., average 9·45 cwt. per ton of steel ingot. For subsequent heat treatment and rolling into normal sections, approximately the same amount of coal was used per ton as was used in the melting process. No doubt the latter figure can be taken at the middle average, or about 7½ cwt. per ton of steel sections rolled.

If these middle average figures—$7\frac{1}{2}$ cwt. in the melting furnace and $7\frac{1}{2}$ cwt. for subsequent operations, total 15 cwt., or 1680 lb., of coal per 2240 lb. of steel sections—are compared with American practice with pulverised coal-fired furnaces, it will be seen that in American works fuel consumption for these operations is about half this amount, and at the same time furnace output is increased some 25 %, and metal loss in rolling operations reduced 50 %.

It was also found by the Committee that the fuel used in blast furnaces for producing pig iron ranged from 21 to 23 cwt. of coke, or the equivalent of 30 to 32 cwt. of coal per ton of iron.

The Committee advanced a practical minimum of 35 cwt. of coal per ton of finished steel sections, and covering the whole process from pig iron to steel sections, as being reasonably achievable, present practice showing that not one firm used less than 40 cwt., and that as much as 50 to 55 cwt. were recorded.

If the ideal set before manufacturers in Great Britain is to be realised, and the overall consumption of coal reduced from between 200 and 250 % down to 175 %—even this figure is high compared with American practice—the use of fuel in pulverised form in the iron and steel industries, if not absolutely essential, should be a ready means of coming near to the practical ideal.

It can be claimed definitely that pulverised coal offers considerable economies over other methods of firing, especially in the reduction of scale losses and in the increase of furnace output. The metal, when brought up to high temperatures, as in skelp bending, bushelling, and tube-welding furnaces, is softer to work. This has also been found to be the case when soaking pits, forging furnaces, sheet and pair furnaces are fired with powdered coal. The heat " soaks " through the metal more uniformly than in furnaces fired with oil or gas, and the ingots, billets or sheets are more easily worked, and can be forged or rolled for longer periods without reheating.

The heating of annealing furnaces by pulverised coal has shown very successful results and attendant economies. At one works in America, thirteen annealing ovens had been so fired for fourteen years (1918), showing exceptionally long life of annealing boxes, and an increase in the rapidity with which furnaces can be brought up to temperature—1600° F. No accident had occurred during the whole fourteen years.

In another case, the same quality of coal as used for the hand firing of sheet and pair furnaces was subsequently used in pulverised form on the same furnaces when converted to this method of firing. The result of the change over to the latter introduced a saving of 320 lb. of coal per ton of sheets rolled, the hand firing being 600 lb. of coal and for pulverised coal firing 280 lb. of coal.

Under certain circumstances, pulverised coal will show an economy over oil, as, for instance, at the Calumet Steel Co.'s Works, for instance, a saving in running costs has been thus effected in the reheating of billets for rolling into steel rails. A reduction of 49 % was made in cost of fuel by using pulverised coal at 11*s.* per ton (2000 lb.), in place of liquid fuel costing $1\frac{1}{2}d.$ per (U.S.A.) gallon, say 26*s.* per ton (2000 lb.), and, in addition, the normal scaling loss of 5 %, with oil firing, was reduced to 2 % when using pulverised coal.

Selection of Fuel and Illustrated Applications.

A careful selection of fuel for metallurgical furnace use need be made only in specific instances, such as for open-hearth steel melting, malleable iron melting and some special cases in which the presence of ash and sulphur may be particularly inadvisable.

Barnhurst advises that, for reheating and open-hearth steel-melting furnaces, fuel of the following composition should be selected :—

	Reheating Furnaces.	Open-Hearth Furnaces.
Volatile water	not under 30%	36%
Fixed carbon	„ „ 50%	52%
Ash	not over 9·5%	6%
Sulphur	„ „ 1·0%	1·0%

For billet-heating furnaces more latitude as regards ash can be allowed, but for piling and bushelling furnaces the ash content should preferably be low, and a coal of the following composition should be used :—

Volatile matter 25 % and upwards; fixed carbon 50 % and upwards; ash below 9 %; sulphur below 2 %.

Where volatile matter is below the limits suggested, it then becomes all the more essential to obtain uniform and fine pulverisation. It has been pointed out elsewhere that, as volatile content diminishes, the degree of fineness of pulverised fuel must be increased, in order to obtain equal firing results in any given combustion chamber.

The question of sulphur in fuel for metallurgical furnaces, and the possibility of contamination, have been dealt with in a paper read before the Columbus Meeting of the American Foundrymen's Association by C. H. Gale, of the Pressed Steel Car Co., McKees Rocks, Pa. He stated that investigations revealed a marked difference in the physical characteristics of steel after pulverised coal was substituted for gas and oil for firing the annealing furnaces. The tensile strength of steel became greater and the carbon and sulphur content increased. The average carbon content before annealing was 0·262 %, after annealing 0·287 %; the sulphur content before annealing was 0·043 %, after annealing 0·052 %. These elements showed the greatest increase after the first annealing. It being thought that possibly the fuel had a case-hardening effect upon the steel, drillings were taken from test bars, and these showed that the increase in sulphur and carbon is near the surface. Samples of malleable iron containing 0·044 % sulphur before annealing showed no increase in sulphur when annealed with gas, but the sulphur content was increased to 0·051 % when annealed with pulverised coal. It was suggested that the type of combustion chamber might make some difference in the results, for the annealing furnaces used had no combustion chambers. The coal was blown directly into the furnace, and the metal could easily absorb the elements from the fuel. Prior to the use of pulverised fuel, the ordinary commercial steel castings made ran from 29 to 31 tons per sq. in. tensile strength. When pulverised coal was used the tensile strength

was increased to 35 tons per sq. in., but when they changed back to oil the tensile strength dropped back to 29 to 31 tons.

Pulverised coal has been applied with success in most cases to nearly all the various types of metallurgical furnaces. Many of the accepted applications are well reviewed and illustrated in a paper read by C. J. Gadd, *Journal of the Franklin*

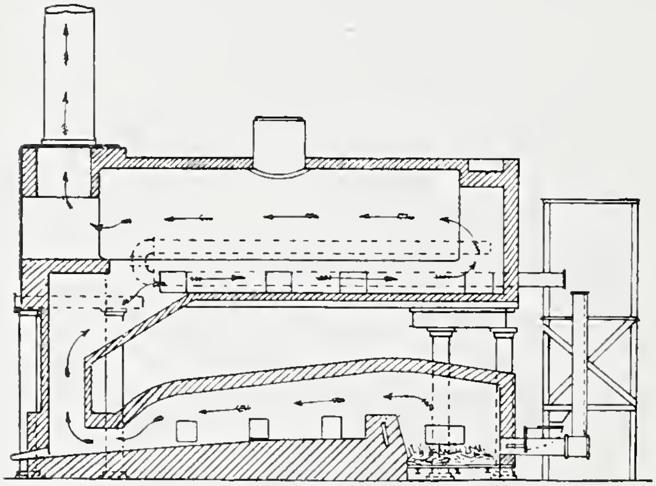


Fig. 170.—Pulverised Fuel Fired Slab-heating Furnace.

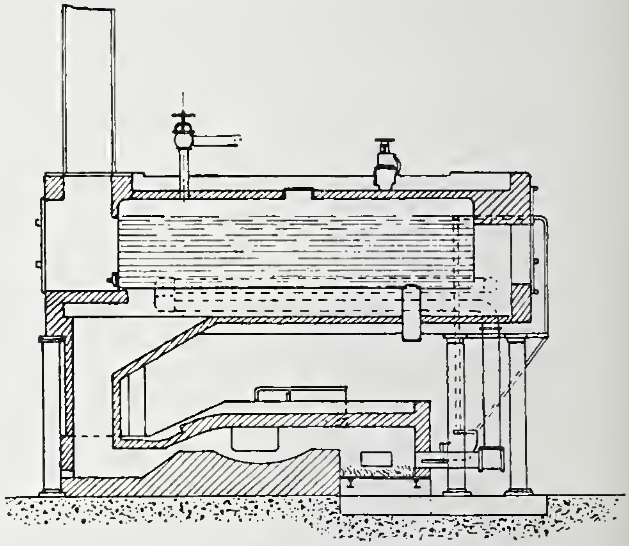


Fig. 170*a*.—Pulverised Fuel Fired Puddled Iron Furnace and Waste Heat Boiler.

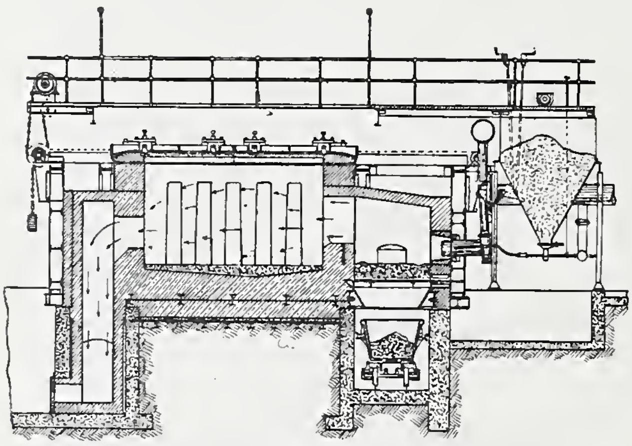


Fig. 171.—Pulverised Fuel Fired Soaking Pit for Steel Ingots.

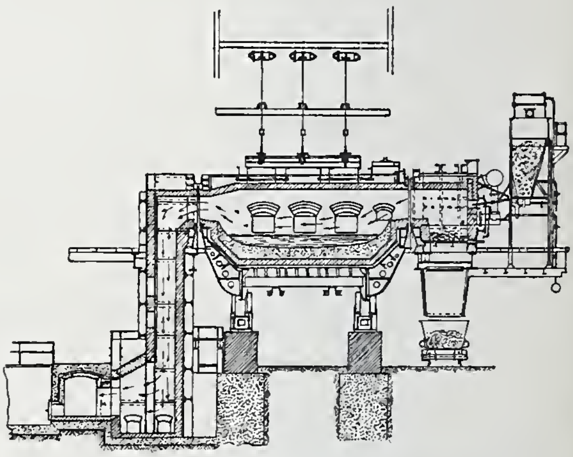


Fig. 171*a*.—Pulverised Fuel Fired Steel-melting Tilting Furnace or Mixer.

Institute, Vol. 3, 1916. Some of these illustrations are reproduced in Figs. 170 and 171. These are self-explanatory, for the drawings clearly show the arrangement of each furnace, and the method of applying pulverised fuel thereto.

A series of sketches representative of general metallurgical furnaces of various types are shown in Fig. 172, and for each typical application of pulverised coal, average figures, based upon a mass of recorded results, are given. It can be generally accepted that this fuel consumption will be obtainable with furnaces of

Comparative Fuel Consumptions of Various Types of Furnaces

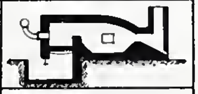
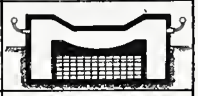
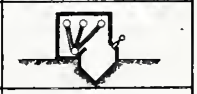
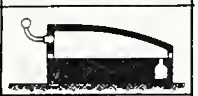
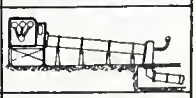
No.	Type of Furnace	Hand Fired Coal per Ton (2240 Lbs.) of Metal	Pulverized Coal Fired per Ton (2240 Lbs.) of Metal	Average Working Temperature	Furnace Outline
		Lbs.	Lbs.		
1	Reheating Furnaces for Steel	710 to 1220	834	1370°C	
2	Reheating Furnaces for Wrought Iron	762	538	1480°C	
3	Puddling Furnaces	2545	1830	1480°C	
4	Busheling Furnaces	815	478 to 538	1425°C	
5	Malleable Iron Melting Furnaces	846	625	1600°C	
6	Malleable Iron Annealing Furnaces	1515	405 to 657	1000°C	
7	Sheet & Pair Furnaces	336 to 542	264	985°C	
8	Sheet Annealing Furnaces	426 to 561	186 to 224	1000°C	
9	Open Hearth Furnaces	497 to 825 Producer Gas fired	457 to 533	1600°C	
10	Steam Boilers	Thermal Efficiency 60% to 75%	Thermal Efficiency 85%	1450°C	
11	Small Forge Furnaces		376	1200°C	
12	Galvanizing Furnaces	379	103	700°C	
13	Rod Heating Furnaces	810	427	1100°C	
14	Continuous Reheating Furnaces	219 to 470	123 to 264	1150°C	
15	Spike Furnaces	778	421	1100°C	
16	Rotary Cement Kilns		560	1600°C	
17	Caustic Pot Furnaces	1000	812		

Fig. 172.—Typical Metallurgical Furnace Applications, showing Working Temperatures and Fuel Saving.

normal sizes, and with coal having a calorific value of about 13,000 to 14,000 B.Th.U. per lb. and 20 to 30 % volatile matter.

Quantity and Fusibility of Ash in Coal.

Reference should be made to Chapter V for general notes on qualities of ash in coal, but as this is a matter of considerable importance in metallurgical furnace design, some further details are mentioned in this section.

In all metallurgical furnace applications, the calorific value of coal and the content of volatile matter are not questions of so much importance as the percentage of ash and its degree of fusibility.

In high-temperature melting furnaces, wherein much of the ash introduced with the coal is drawn off with the slag, about 10 % of the ash of a fuel containing, say, 10 % ash in the natural state will usually accumulate in the flue or pocket at the exit of the furnace and between this point and the flue damper. This deposit should be removed periodically, so that its accumulation will not affect the draught of the furnace.

On the subject of fusibility of ash in coal, a bulletin has been published by the Bureau of Mines, Washington, recording the results obtained by W. A. Selvig and A. C. Fieldner, when testing numerous samples of American coal. The following table, in which five typical samples of ash are analysed, sums up the range of practical fusibility of coal ash.

Sample No.	Softening Temperature °F.	Analyses of ash, percentage of :								
		SiO_2.	Al_2O_3.	Fe_2O_3.	TiO_2.	CaO.	MgO.	Na_2O.	K_2O.	SO_2.
1	2,060	30·7	19·6	18·9	1·1	11·3	3·7	1·9	0·5	12·2
2	2,320	46·2	22·9	7·7	1·0	10·1	1·6	0·7	0·8	8·9
3	2,500	49·7	26·8	11·4	1·2	4·2	0·8	1·6	1·3	2·5
4	2,730	51·0	30·9	10·7	1·9	2·1	0·9	1·0	0·4	0·6
5	2,900	58·5	30·6	4·2	1·8	2·0	0·4	0·7	0·9	0·9

Fig. 173 shows a sectional view of a continuous reheating furnace. Attention is drawn to the different temperature zones marked on the drawing, from which points the ash samples (Fig. 174) were taken. The formation of hard and soft ash cones, or "stalactites," on the roof of the furnace indicates that much of the fine dust carried into the furnace is carried along under the crown, and it is not until the gases have become cooled that any appreciable accumulation of ash dust is found on the hearth of the furnace. In this particular furnace it was found that 40 % of the ash recovered was deposited on the combustion chamber hearth, 20 % as liquid slag, 30 % as roof stalactites in hard and soft formation, and 10 % as dry fine dust at the charge end of the furnace and flues.

Selection of Refractories.

It has already been pointed out that conflicting reactions between the constituents of firebrick and those of the fuel to be used should, as far as possible, be

CONTINUOUS BILLET HEATING FURNACE SHEWING FUSED & SOLID ASH & DUST ZONES.

[To face p. 300.

avoided by careful selection of the refractories available. A good quality of firebrick of any known refractory can usually be used for either high- or low-temperature work when combustion areas can be made sufficiently large, but, for confined combustion chambers, silica bricks, for instance, may be quite unsuitable.

Consider a brick containing 13·2 % alumina, 82 % silica, 1·2 % sesquioxide of iron, 3 % loss on fusion. Such a refractory is exceptionally high in silica, and its expansion at high temperatures would probably cause trouble in small high-temperature furnaces. For large furnaces, provision can be made for expansion. Thin pieces of wood between the bricks are sometimes used, the wood burning out or becoming compressed as the furnace is brought up to temperature. A brick of this composition would also break or chip out when subjected to rapid variations in temperature. For general purposes, firebrick used in America for pulverised fuel-fired furnaces is usually made from a first-class grade of fireclay, as, for example, the Mt. Savage refractory brick, which has an average analysis of 38·14 % alumina, 41·93 % silica, 13·1 % sesquioxide of iron, 13·80 % loss on fusion, 2·39 % fluxing materials. This brick is infusible up to the point of 1790° C.

Refractory firebricks approximating to this analysis are usually available, as, for instance, bricks from the Ardennes, which show an analysis of about 34·77 % alumina, 39·69 % silica, 1·80% sesquioxide of iron, 1·3 % loss on fusion, 3·30 % fluxing materials, the brick being infusible also up to the point of 1790° C.

Utilisation of Waste Heat.

Fuel economy in a metallurgical works should embrace, wherever possible, the utilisation of the heat content of waste gases from furnaces.* This valuable source of heat is often lost, 70 to 80 % of the original heat value of the fuel being carried away in the waste gases from the furnaces, instead of being utilised in some way, as, *e. g.* in raising steam. If the raising of steam is of no practical use, then air heaters should be inserted, by means of which the air required for combustion of the coal can be heated and a valuable saving in fuel thereby effected.

In the making of puddled iron, 1600 lb. of coal per ton of iron will be used when the air is supplied at, say, 50° F., but with air preheated to 500° F. or 600° F., the quantity of coal used will be reduced to 1100 or 1200 lb.

Welles and Jacobi in their recent paper on "Pulverised Coal as a Fuel for Boilers," read at the December Meeting of the American Society of Mechanical Engineers, New York, quote figures in support of this contention. Reference is made to certain tests carried out to determine the value of preheated air, as affecting the efficiency of boilers. They say :—

"Comparative tests on a 250-h.p. boiler using combustion air at 65° F. and 750° F. with powdered bituminous coal showed that, other things being equal, with air at 65° the evaporation was 7·7 lb. per lb. of fuel, and the temperature of escaping gases 528°, while with the 750° air the evaporation was 9·17 lb. per lb. fuel, and the temperature of the escaping gases 475°. On the basis of the normal boiler rating

* See *The Utilisation of Waste Heat for Steam Generating Purposes,* by A. D. Pratt, American Society of Mechanical Engineers, Dec. 1916.

this performance indicated a gain of 15 % with hot air and a loss of 12·2 % with air at the ordinary temperature."

In America, it is more usual than in this country to instal waste heat boilers in connection with most classes of melting or heat treatment furnaces. This is always the practice with puddling furnaces, and, with powdered coal firing, the boilers receive the highly heated clear gases from the melting furnaces, whereas in hand firing there are periods of thick smoke. Waste heat boiler rating, therefore, is, if anything, increased when powdered coal is used, and full steaming can be maintained during the removal of the ball or during charging, if a supplementary powdered coal burner is fixed at the uptake flue to the boiler. The use of a supplementary burner removes one of the principal objections to the installation of waste heat boilers in conjunction with metallurgical furnaces of intermittent operation, *i. e.* the irregularity in steaming. It is possible to fire puddling furnaces with pulverised fuel so that only the slightest indication of the smoke is visible at the stacks. A view of a puddled iron works in full operation is given in Fig. 180.

The application of powdered fuel to high-temperature furnaces, open-hearth melting, puddling, forging and welding, billet-heating furnaces, with the exception of those of the continuous type, and cement kilns, makes it possible to instal waste-heat boilers. The temperature variation in such furnaces is very small, comparing favourably in this respect with the uniform temperatures obtainable with gas and oil firing. The fine unfused ash dust passing through to the waste heat boiler from the furnace causes very little inconvenience.

In connection with copper-smelting furnaces, waste-heat boilers are invariably used, and it is stated that boiler tubes are cleaned no oftener when using pulverised coal than when the furnaces are hand fired. The ash carried over in the waste gases settles in the flues and is cleaned out once a day. In high-temperature melting furnaces, approximately 50 % of the total ash content remains in the furnace and is run off in the slag.

In the majority of cases, considerably more than 50 % of the total heat developed in a high-temperature metallurgical furnace passes out with the waste gases. Every opportunity should be taken to instal a waste heat boiler when the steam raised therein can be usefully employed.

At the Lebanon works in America, where puddling furnaces are fired with pulverised fuel of 13,000 to 14,000 B.Th.U. value, $8\frac{1}{2}$ to 9 lb. of water are evaporated in the waste heat boilers per lb. of fuel fired in the puddling furnaces. This would indicate that the percentage heat value passing out to these boilers approached 70 % of the total value of the fuel as fired.

The steam raised in these boilers, which are located over a very wide area of the works, is collected in one return steam main and utilised for the generation of electric power.

Blast Furnaces and Reduction of Coke Consumption.

Although little has been accomplished in the way of using pulverised coal for smelting iron ore in blast furnaces, certain progress has been made in this direction in connection with copper, nickel, and lead smelting furnaces.

FIG. 174.—CLINKER AND ASH FROM BILLET-HEATING FURNACE.

A. Hard Clinker on Coke Bed. B. Liquid Slag. C. Hard Roof Stalactite. D. Soft Roof Stalactite. F. Fine Dust.

[*To face p.* 302.

That the presence of lump coal in the charge of an iron ore furnace may be beneficial has been proved in Germany, and in that country it is the opinion that pulverised coal firing may eventually be adopted as a means of reducing the consumption of the more expensive metallurgical coke. An application of this type is shown in Fig. 175, and the burners or injectors used in Fig. 175*a*.

F. Lange (" Stahl and Eisen " : *Iron Age*, September 2nd, 1918) stated that, at the Phoenix Works at Kupferdreh, from 4 to 8 % by volume of lean and anthracite coal from a neighbouring mine was mixed with the iron-ore charge. This addition

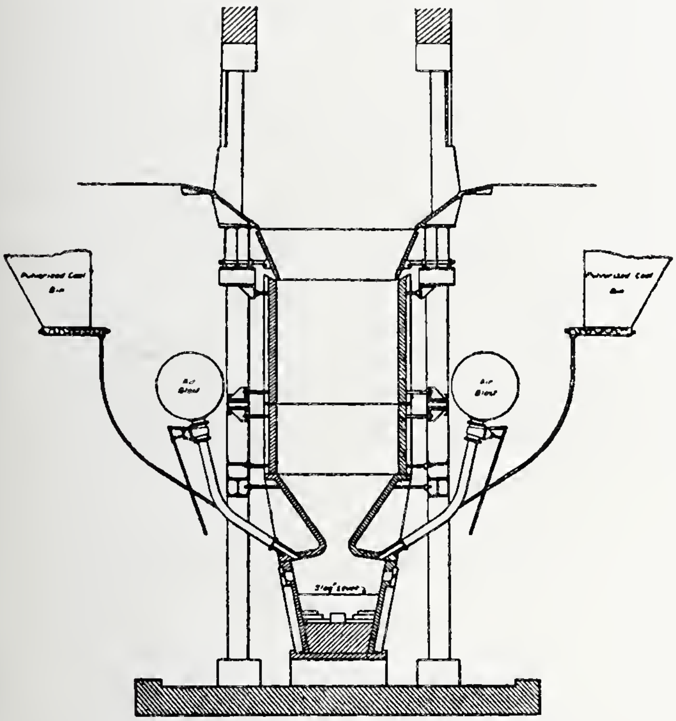


FIG. 175.—Application of Pulverised Coal to Blast Furnace. (*Colliery Guardian.*)

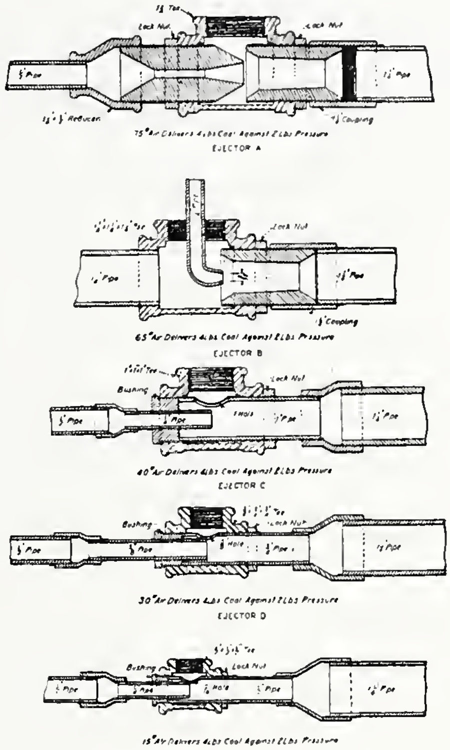


FIG. 175*a*.—Types of Injector Fuel Burners used on Blast Furnace. (*Colliery Guardian.*)

of raw coal was always found to have a good influence in the production of foundry iron, hematite, and ferro-silicon, and particularly on the silicon contents of the metal. A similar addition is also to be recommended in the production of ferro-manganese, especially when brown ore is used that contains the manganese as the higher oxide. Moreover, the coke can be partly replaced by lump anthracite, with a saving in cost depending on the prices of the materials. As a sequence to these discoveries the introduction of pulverised coal through the tuyères directly into the furnace is believed by Lange to have a good future, for by this means the temperature in the melting zone will be considerably increased, and the following advantages are to be expected :—

(1) The cost for fuel will be smaller, because the coke is partly replaced by the

much cheaper coal. At Kupferdreh, if one-sixth of the coke were replaced by the dry powdered coal, the saving would be 1·25 marks per ton of pig iron.

(2) The production of ferro-silicon, ferro-manganese, ferro-chrome, etc., will be made easier, and with ferro-manganese there will be less loss of manganese in the slag.

(3) The top temperature will be lower, because less fuel will be added with the charge.

The influence of the fine coal may be compared with that of an increased blast temperature, because its effect is developed directly at the tuyères. Its use is particularly recommended for small blast furnaces, which are preferable when fine ores are to be used. On account of the heat developed by the coal the blast temperatures could be lowered, so that the old pipe stoves would be preferable, on account of the regularity of temperature thereby obtained.

In conclusion, it is pointed out by Lange that the powdered coal provides a suitable means of heating the stoves when starting up, or when the gas supply is insufficient for any reason.

In America, W. L. Wotherspoon has given great attention to this development in connection with non-ferrous ore smelting, and he records the fact that one of the Tennessee blast furnaces has been run upon pulverised coal alone, the coal ratio being 3·8 % of the charge as against 6 % and upwards for metallurgical coke.

To quote again from the British Association Fuel Economy Committee's report, an analysis of twenty-one returns from blast furnace companies shows that the coke and equivalent coal consumption per ton (2240 lb.) of pig iron of the various well-known brands or qualities, was :—

	Quality of Iron.			
	Cleveland.	Lincolnshire.	Midlands. Basic.	Hematite.
Coke consumption, cwts.	23·5	33·0	26·0	21·33
Equivalent coal consumption	32·65	47·0	37·0	30·0

If, as is stated above by Lange, the quality of metal produced can be improved by the use of coal as fuel for blast furnaces, and if, as proved by Garred in the following results, coke used for this purpose can be reduced by 40 % (in copper-nickel smelting), there should be every inducement to extend this application to the iron-smelting furnaces, wherein so much of the costly metallurgical coke could be replaced by pulverised coal, costing perhaps but half the amount paid per ton for coke.

The following information has been extracted from *Engineering*, November 21st, 1919. The progress made during recent years and the results obtained in applying pulverised coal as a blast furnace fuel were fully reviewed in that issue, wherein many illustrations were given of different types of tuyères used during the course of the developments.

"Experiments (by Garred) at the smelter of the Tennessee Copper Co. were decided upon early in 1918, one of their standard blast furnaces, 22 ft. 6 in.

long by 60 in. wide, being used. Ten tuyères on one side of the furnace were equipped for the use of pulverised fuel, and the first test run of importance started on 22nd April, and was continued until 4th May, during which period the percentage of coal to the charge was 3·8, as against 5·7 of coke used on the other furnaces during the same period, when operating with a similar charge. The second test run started 9th May, and continued until 24th May, when the percentage of coal used was 3·6, a very small amount of coke being used intermittently.

" A third test run was then made, feeding a little coke on the side of the furnace where no coal was fed previously, as it had been found there was a tendency for crusts to form on that side of the furnace. It was then decided to apply the coal at 10 tuyères on each side, but experimental work was postponed, owing to the possibility of some unconsumed carbon in the furnace gases causing discolorisation and affecting the quality of the acid, which is an important product of the company, particularly during the war, when a portion was used in the manufacture of high explosives. The war requirements in this connection no longer existing, the company returned to the experimental work in January, and are continuing, with various modifications, the methods of applying the coal.

" Following the work of Garred, the International Nickel Co. decided in June 1918 to carry out experiments in the blast-furnace department of their smelter at Copper Cliff, Ontario. It was decided to utilise one of their standard blast furnaces, which are 25 ft. 6 in. long by 50 in. wide. The furnace bottom is lined with magnesite brick to within 14 in. of the centre of the tuyères; the two lower rows of jackets are of cast iron with water-cooled pipes, and the two upper rows of jackets are of the standard water-cooled steel type. The furnace has 48 six-inch tuyères, 24 on a side, spaced about 12 in. centres. These are connected to a main bustle pipe with 6-in. galvanised branch pipes fitted with canvas sleeves. The bustle pipe is supplied, by an offset, from the main delivery pipe, which feeds seven other furnaces, the normal pressure of air carried at the tuyères being 23 oz. to 24 oz.

" The furnace charge consists mainly of a refractory copper-nickel sulphide ore, a large proportion of which is delivered from the company's roasting plant.

" The furnace, under normal conditions of smelting, treats about 500 tons of charge a day, utilising 60 tons of coke, the average consumption for six months being 12·5 % of the charge."

Extended runs with pulverised coal firing have shown that the coke consumption can be reduced by half and the deficiency made up with the less expensive pulverised coal.

A short article appeared in *Mining and Metallurgy*, October, 1922, by E. H. Hamilton, relative to the use of powdered coal in the Lead Blast Furnace at Midvale, Utah, U.S.A.

The furnace used is one of a number, 48 in. dia., 160 in. in height, and had been running continuously for seven months on powdered coal and coke; it was then stated that the furnace was still in excellent condition.

Apparently, the fuel feeder finally adopted by this Company, after using several standard makes of burners, is of the syphon type, as mention is made of the fact that

"injector air" at 15 lb. pressure is used in addition to the main air supply at 40 oz. pressure.

It is stated that the application of pulverised coal to a lead blast furnace is more difficult than its application to a copper blast furnace, as it is essential to maintain a continuously reducing atmosphere in the lead furnace and, consequently, the control of coal supply must be exact and reliable.

It is found that with a constant coal feed, if the action of the furnace becomes slower for any reason, the continued coal feed damps the furnace still further, and the slowing-down action becomes cumulative. In the same way acceleration is cumulative. It is all the more essential, in view of these experiences, that supply of fuel should be capable of exact regulation.

The average fuel consumption in relation to the weight of charge has been found to be 9 % of coke and 4 % of coal when working with the mixed fuel. The output of the furnaces is reduced about 6 % under these conditions, and the total weight of mixed fuel is about the same as when coke alone is used. The average fineness of pulverised coal used is such that 75 % will pass through a 200-mesh screen.

At the Cerro de Pasco Copper Co.'s works in Peru, where formerly about 65,000 tons of metallurgical coke were used annually, the application of pulverised coal has resulted in a very considerable saving. When the initial tests were carried out on one of the five blast furnaces, it was found that a 25 % reduction in coke could be made. By making various alterations in the method of introducing the pulverised coal, the installation has been brought to a point at which 50 % of coke can now be replaced with pulverised local coal.

In a fourteen-hour run, for which the normal coke charge was previously 31,000 lb., the quantity of fuel now used is 17,000 lb. of coke and 8900 lb. of pulverised coal, In a fifty-hour run, the present normal consumption of coke is 61,800 lb., together with 14,000 lb. of pulverised coal, this total amount of mixed fuel replacing 114,000 lb. of straight coke. An extremely valuable saving in both cost and quantity of fuel for any country, and especially so when metallurgical coke is poor, expensive, or scarce.

A trial plant has been installed at the Smelters of the Union Minière du Haute-Katanga, Belgian East Africa, for the production of pulverised coal to be applied to the Copper Blast Furnaces under the Garred-Cavers patents, whereby the expensive metallurgical coke will be greatly reduced by the use of pulverised local coal.

Copper-Smelting Reverberatory Furnaces.

Some of the largest coal-pulverising plants in existence are found at the various copper-smelting works in America. At the Anaconda Copper Co.'s works from 1000 to 1200 tons of coal are pulverised daily when the smelting furnace plant is working at full capacity.

The plant installed at The Nevada Consolidated Copper Smelter works in 1917 is of the Holbeck system, with loop mains for the conveying of pulverised coal to the furnaces, the main steam boilers, and the waste heat boilers, in the various departments. The milling plant consists of seven Bonnot air-separation mills, each

of from $4\frac{1}{2}$ to 5 tons capacity per hour, the mill plant being operated at an average daily rate of 550 tons (2000 lb.) of raw coal.

The use of pulverised coal in copper reverberatory smelting furnaces has become general practice in America. Originally built for oil or hand firing with coal, most of the large reverberatory copper-smelting furnaces have been converted during recent years to firing by means of powdered fuel.

In January, 1915, the American Institute of Mining Engineers published a paper on this subject by David H. Browne, in which he reviewed previous attempts to apply pulverised coal to copper-smelting furnaces, and recorded fully the successful methods introduced by him in connection with the reverberatory furnaces at the works of the Canadian Copper Co., Copper Cliff, Ontario. At these works smelting had been carried out for twenty years in blast furnaces.

In 1906 and 1908 two previous investigations and actual applications of powdered coal had been made, one by Sorensen at the Highland Boy Mines at Steptoe Valley, and one by Charles Shelby on furnaces at Cananea.

Fuel ratios for hand firing were then about 4·1 tons of copper to 1 ton of coal. After applying the same grade of coal in pulverised form, a ratio of 7·24 tons of copper to 1 ton of coal was obtained. Furnaces at the Canadian Copper Co.'s works were put into operation during the winter 1911 to 1912, the results for the first three months being :—

	Total Charge.	Charge per Day.	Ratio.
January	12,897 tons	416 tons	5·0 tons copper per ton fuel.
February	12,149 ,,	434 ,,	5·65 ,, ,, ,,
March	14,195 ,,	458 ,,	6·77 ,, ,, ,,

The latest practice at these works, since adopted by other companies, is to brick up all side charging doors, and to provide a shallow channel along each side above the roof of the furnace. Charging pipes are connected to the channels through which the copper ore is introduced into the furnace. The ore falling through these charging pipes adheres to the side walls of the furnace, and forms a protecting blanket over the brickwork. In this manner the life of the furnace walls is very greatly increased.

The furnace at the Canadian Copper Co.'s works, illustrated in Fig. 176, is some 112 ft. long by 20 ft. wide inside. The coal used at the time of making the tests recorded was a good quality of slack, showing : Volatile matter, approximately 34 %; fixed carbon, approximately 55 %; ash, approximately 9 %; sulphur, approximately 1 %; B.Th.U., approximately 13,500.

In pulverised form 95 % passes through a 100-mesh, and 80 % through a 200-mesh screen. The furnace is fitted with five burners, each delivering about 13·5 tons of coal per day, or 19 lb. per minute.

In the same journal of the American Institute of Mining Engineers, Louis V. Bender writes on the work carried out at the Washoe Reduction Works of the Anaconda Copper Co. Following upon the success made by Browne in Ontario, one of the Anaconda furnaces was adopted for pulverised coal firing, in 1914. The follow-

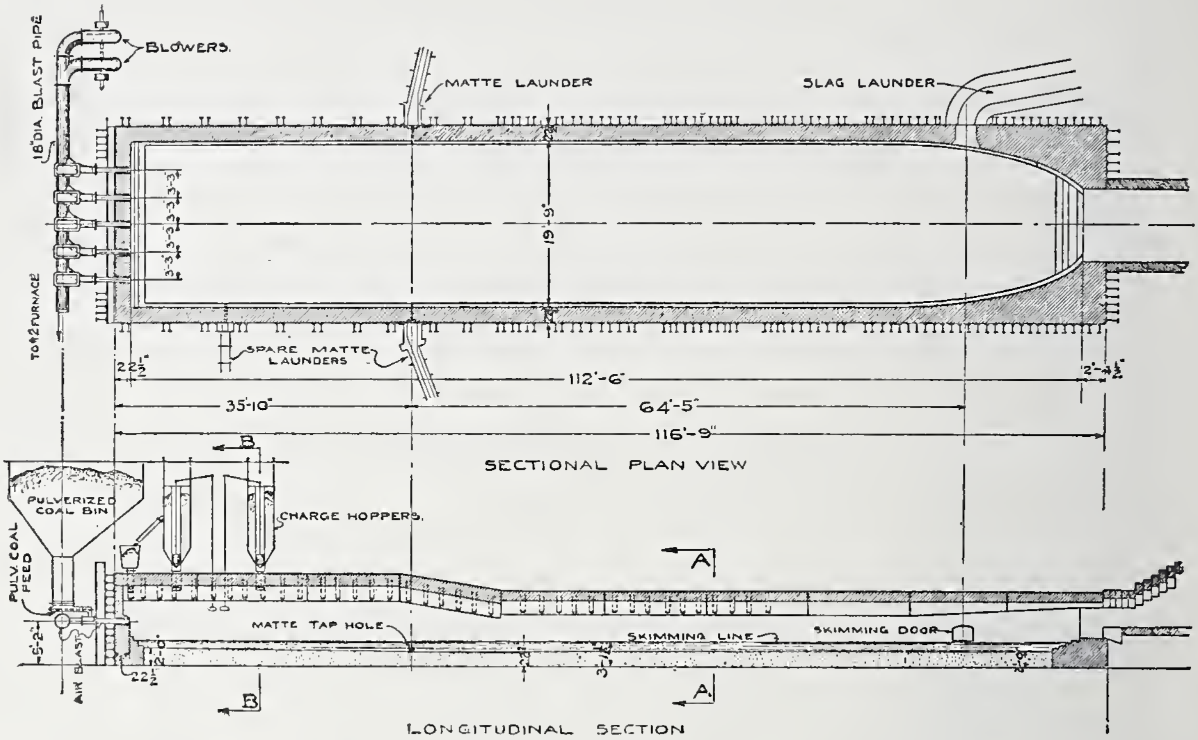


FIG. 176.—Pulverised Coal Fired Copper-smelting Reverberatory Furnace at the Canadian Copper Company's Copper Cliff Works, Canada.

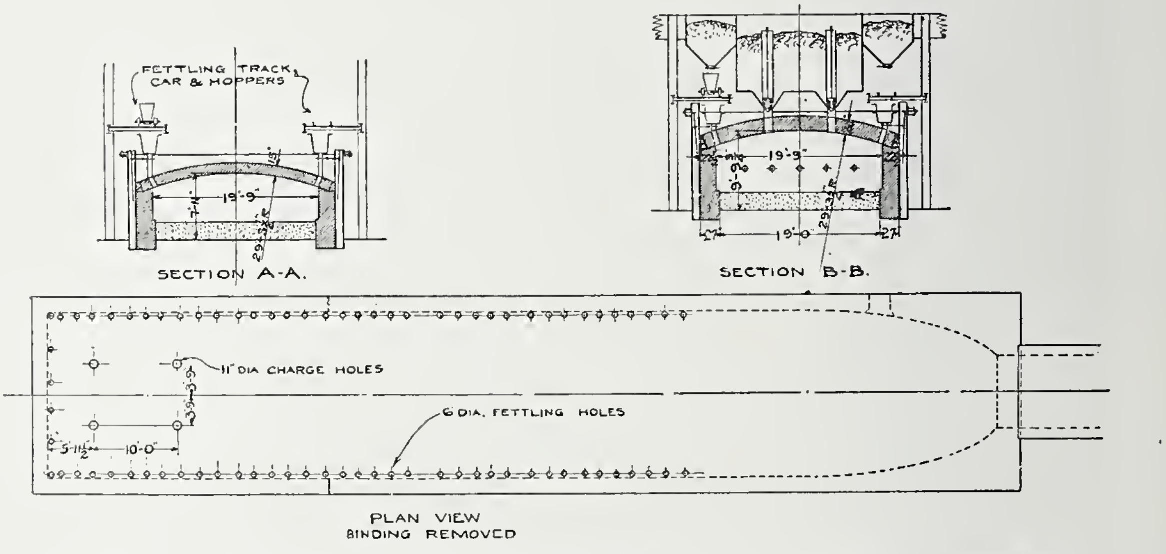


FIG. 176*a*.—Details of Reverberatory Furnace as above, showing method of Charging and Side Fettling Holes.

(*David H. Browne.*) (*American Institute of Mining Engineers*, February 1915.)

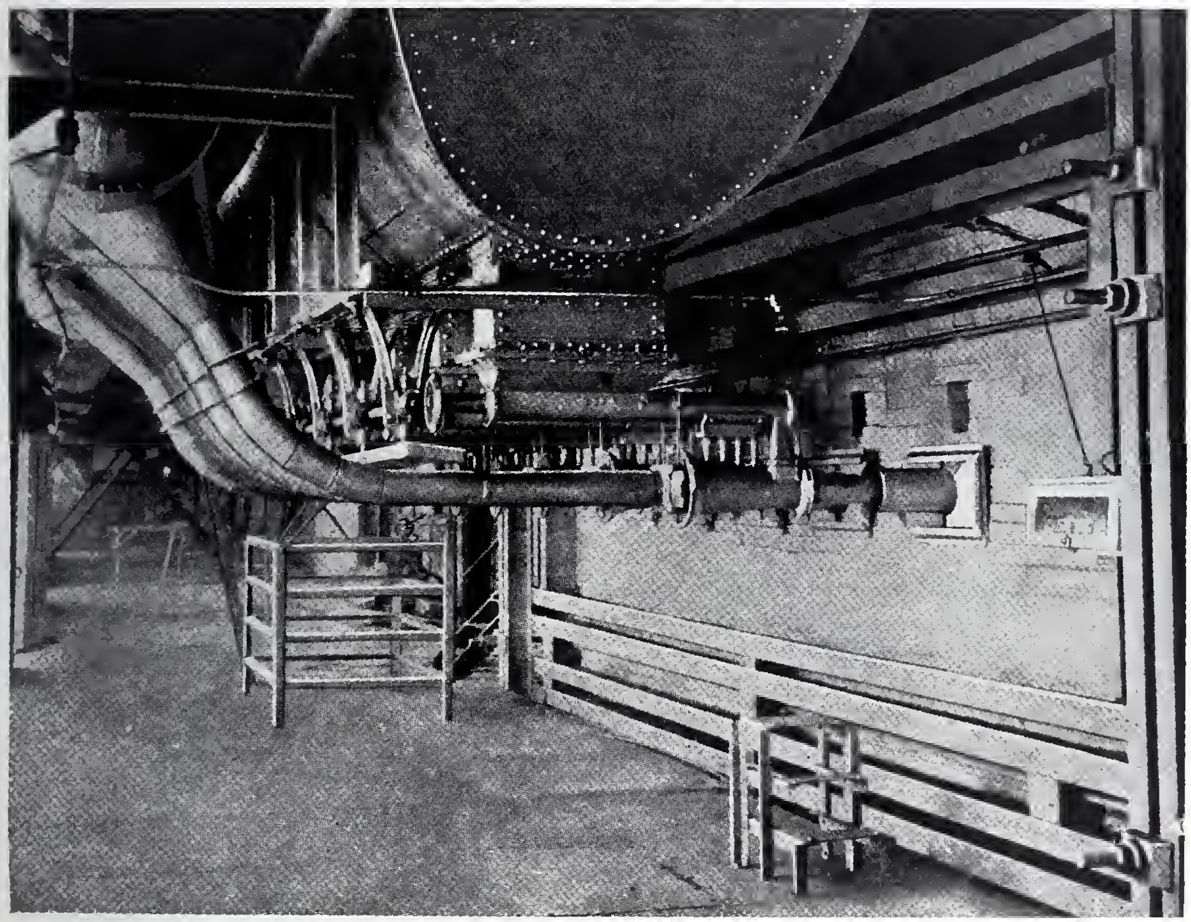


FIG. 177.—FULLER SCREW FEEDERS AND BURNERS AS APPLIED TO REVERBERATORY COPPER-SMELTING FURNACES.

The Fuller Engineering Co.] [*The Fuller Lehigh Co.*

[*To face p.* 308.

ing figures, taken from Bender's paper, show the exceptionally good results obtained as against hand firing.

	Moisture.	V.C.M.	F.C.	Ash.	B.Th.U. dry.	Length of Test Days.	Tons Smelted per Day.	Fuel Ratio Pulverised Coal.
Lockray . .	8·0%	29·3	41·8	20·9	10,350	12	409·4	5·38
Bear Creek . .	9·0%	35·5	43·4	12·7	11,500	18	406·7	5·57
Diamond Ville .	5·6%	41·4	44·9	8·1	12,960	30	475·8	7·24

On the new Anaconda furnaces it was expected to reach a fuel ratio of 7·5 for straight through work.

The advantage of using fuel in powdered form as against hand firing is shown by the following figures.

.	Tons Smelted per Furnace per Day.	Total Tons Smelted.	Tons Coal.	Fuel Ratio
Furnace hand fired . . .	250·96	7,260·31	1,870·94	3·88 tons of charge
,, pulverised coal fired .	475·75	14,272·52	1,984·77	7·08 ,, ,, ,,

Some of the American copper-smelting reverberatory furnaces are of considerable size, the largest in operation a few years ago being one 144 ft. in length, with an inside width of 25 ft. From this furnace, using pulverised coal, a daily output of 750 tons is obtained. It is believed that at the works of the Anaconda Copper Co. there are pulverised coal-fired furnaces 175 ft. in length. As a direct result of firing with pulverised coal in 1915 the cost per ton for smelting was reduced by 50 cents. Fuller feeders and burners as arranged for a copper-smelting furnace are shown in Fig. 177.

Of the 1,396,000 tons of copper computed to have been the world's production in 1916, some 860,647 tons were produced in America, and nearly the whole of this amount was smelted in pulverised coal-fired furnaces.

If one considers the amount of coal required to smelt, say, one million tons of copper ore, on the basis of the figures given by Bender, the comparison between hand-firing and coal-dust firing would be :—

Hand-fired reverberatory furnaces	257,732 tons of coal.
Coal-dust fired ,, ,,	141,242 ,, ,, ,,

Thus, over 100,000 tons of coal would be saved per million tons of charge smelted.

Pulverised coal firing can also be very successfully applied to copper-melting furnaces. A test was made at one of the American works upon one of a number of 200-ton hand-fired furnaces; the output under these conditions is about 190 tons of copper anodes cast per 26 hours, the coal consumption being 300 lb. per ton (2000 lb.) of copper melted and cast. After changing over to pulverised coal firing, the same charge, 190 tons, has been melted ready for casting in about 10 hours.

The casting equipment at these works may have been redesigned to take this

doubled output, but, at the time these tests were made, the casting plant, as used in conjunction with the hand-fired furnaces, did not permit of the copper being cast under 20 hours from the start of the heat. Even so, the fuel consumption for the pulverised coal fired furnace was only 200 lb. per ton of copper cast.

Open Hearth Steel-Melting Furnaces.

Although there are quite a number of steel works in America at which steel-melting furnaces are fired with pulverised fuel with every degree of success and profit from the system, yet at others results have been neither good enough nor bad enough for any really pronounced opinion to be formed, while at some works this method of firing has proved a decided failure. In cases where success has been achieved, either the fuel has been specially suitable, *i. e.* high quality, low ash, and low sulphur, fuel; or the furnaces and arrangement of regenerative chequer chambers have been such that ash settlement has given little trouble. It is not to be disputed that when conditions are suitable for pulverised coal firing, considerable fuel and other economies can be made.

Established practice shows that with coal of 14,000 B.Th.U. value, 0·3 of a ton of coal (9,400,000 B.Th.U. value) is an average quantity of fuel used in the gas producer per ton of steel melted. But practical results have proved that for the same class of coal, the same nature of charge, and the same capacity of furnace, 0·2 of a ton (6,272,000 B.Th.U.) per ton of steel melted is required for pulverised coal firing, a saving of $33\frac{1}{3}$ % in favour of the latter.

Each system has its rightful sphere of usefulness, and each has its several faults and difficulties.

It is stated of the new types of modern mechanically fed gas-producers, such as those of the Morgan Construction Co., of Worcester, Mass., in which ash-removal ploughs are employed in addition to mechanical feed gear, that one man can tend a battery of six 10-foot producers. This Company claim for their most recent 10-foot producers a duty equal to 3000 lb. of coal gasified per hour, giving gas of 178 B.Th.U., as against 1600 to 1700 lb. of the same quality of coal gasified in most of the well-known mechanical producers, making gas of about 145 B.Th.U. per cu. ft. This means that one man on an eight-hour shift will tend a " Morgan " producer plant handling 144,000 lb. of coal, and at 75 % overall heat value efficiency at the furnace, a coal equivalent of 138,000 lb. of coal is burned in the furnaces.

For the production of pulverised coal, it would require three men per shift of eight hours for a plant capacity of eight tons per hour, or 143,360 lb. per eight-hour shift. Normal practice with the more ordinary types of mechanically fed producers is about one-fourth the amount of coal handled per man as compared with the latest types of " Morgan " producers; or, say, 35,840 lb. per eight-hour shift per man for mechanically fed producers, and for hand-fired producers about 10,000 lb. of coal.

It must be definitely stated that the use of pulverised coal as a means of firing steel-melting furnaces is only applicable to the melting of basic steel. This fact has been demonstrated, and, from all practical points of view, proved in America. The reason for ruling out acid steel furnaces is succinctly put by Yaneske in correspondence following the author's Iron and Steel Institute paper :—

" When the application of powdered coal to the acid open-hearth was considered, however, it seemed that less oxidation of the elements to be removed from the charge would be effected by the flame during both melting and oreing periods than with producer-gas. As the removal of carbon by gas oxidation amounted to about 50 % in ordinary practice, using producer-gas, a considerably longer time would therefore be taken in working the charge if powdered coal were used, and much more iron ore would be required. The carbon in the ash which would come in contact with the slag would also cause the gradual reduction of FeO from the slag, and the removal of FeO would be accelerated by the action of CaO if the fuel was high in limey ash. In that way a very thick siliceous slag would result and the process be further retarded. If that were borne out in practice, the saving in fuel by the use of powdered coal would be more than counterbalanced by the lengthening of the process, and it would perhaps be advisable under those circumstances to work with a much higher percentage of scrap with a powdered coal flame than in ordinary practice."

A good quality of fuel is essential for success in firing open-hearth furnaces, and a suitable analysis is : volatile matter, not under 36·00 %; fixed carbon, not under 52·00 %; moisture, not over 1·25 %; ash, not over 6·00 %; sulphur, not over 1·00 %.

Success or failure in applying pulverised coal to open-hearth steel furnaces depends entirely upon the nature of the fuel used, the arrangement of the furnace, and flue and chequer design. This matter has been discussed in the technical Press, and *Blast Furnace and Steel Plant* gives the following summary :—

" While for heating furnace work many kinds of coal are available for powdering, the list of available coals for open-hearth work is small. Small sulphur content and small ash content, together with high volatile content, are extremely desirable. Many failures of powdered coal for open-hearth work are due to the purchasing of a cheap coal. Regenerators must be so designed that fused ash can be deposited in a removable slag pocket before the flue gases reach the chequer work. The latter must be fairly open. Good success has been attained by making the gas passages tubular, without dead spaces or projecting corners, which may favour deposit. From snowstorms it is known that snow drifts into places where the air is stagnant, and accumulates there. Ash in flue gases does the same. Easy bends of tubular construction and without sudden changes in cross-section are therefore recommended.

" To avoid deposits of ash, the coal must be very finely ground. The finer the coal, the slower the air current in which it will remain afloat. Installations of grinders much larger than absolutely necessary are recommended, because overloading of pulverising apparatus causes coarse grinding. If the grinding is fine enough, if the regenerators are properly designed, and if a good coal is burned, practically all of the ash is carried out through the stack in the shape of a scarcely visible whitish haze. If these precautions are not used, and particularly if a cheaper grade of coal is used, frequent repairs to the furnace regenerator are necessary : in some places the regenerators have to be cleaned out every four weeks. There is

consequently no saving in using a cheap coal, particularly in times of great demand for steel. The gain due to the avoidance of frequent shut-downs pays several times over for the difference in the price of coal."

Experiments have been conducted with steel-melting furnaces fitted with only one burner, or one set of burners, the flow of gases being in one direction only, and it was at one time thought that non-reversing furnaces on these lines would prove a success. The hopes entertained that this simplification in steel furnace design could be established have not been substantiated.

Although it is quite possible to melt steel when pulverised coal is introduced with cold air, it is not sound practice to do so, even when the waste heat can be efficiently transferred to the raising of steam. With cold air the time of melting is prolonged, and preheated air supply is now always provided through the usual means of regenerative chequers, preferably redesigned to allow for increased gas passage in order to minimise dust settlement.

With regard to sulphur contamination of steel, this is no greater than with producer gas. The sulphur contained in the coal is split up into such fine particles that it is immediately burned, and the products pass off in the waste gases. Coal containing 1·25 % sulphur has been used, and the analysis showed only 0·035 to 0·04 % of sulphur in the steel produced. Coal containing up to 3·67 % sulphur has been used, and ash up to 20 %. With the latter, a cold charge of 60 tons has been brought out in 12 to 13 hours and hot charges in 7 hours.

In a paper presented by N. C. Harrison, the General Superintendent of the Atlantic Steel Co., Atlanta, Georgia, U.S.A., who is perhaps the pioneer in America in making the most complete success of pulverised coal firing for steel-melting furnaces, the advantages of this system, as against producer-gas firing, are set out as follows :—

" (1) In the case of the pulverised fuel all the heat units in the coal are consumed in the furnace, while in the case of the gas-producer some 18 to 25 % of the heat units is lost in the producer itself when converting the coal into gas.

" (2) Open-hearth furnaces using powdered fuel operate on a fuel consumption equal to the best producer-gas practice, and much better than the average of the older plants in the States ; at the author's plant about 50 % less.

" (3) Coal can be pulverised in plants of about 100 tons daily capacity and delivered to the furnace for about 50 cents (2*s.* 1*d.*) per ton, which is about the same as the costs for gasifying coal in gas producers.

" (4) The use of pulverised fuel in metallurgical furnaces is steadily increasing.

" (5) In the author's plant the pulverised-coal open-hearth furnace has been shut down more often than the producer-gas furnace of the same size. This has been due to chequers and slag pockets filling up with cinders and slag after about eighty heats ; these troubles, however, are being gradually overcome by decreasing the size of the uptakes and enlarging the slag pockets, thereby holding the gases in the furnace longer and passing them slowly through the large slag pockets, so that the heavy particles can settle, and now, only the fine particles are going to the chequers ; they are being blown off daily by compressed air. By this means it is

expected to get a much longer life out of the furnace, since the filling up of the chequers has always been the deciding factor in the length of run of the furnace.

"(6) Sulphur does not give any trouble as long as there is a good draft and the furnace is working hot, as the author's plant is now using coal with over 1 % sulphur, and getting good results, although when chequers get clogged up towards the end of the run and the furnace begins to blow, due to lack of draft, there is trouble with the bath taking up sulphur.

"(7) The pulverised-coal open-hearth furnace is under complete control of the first helper as to the amount of coal being used at all times, and also as to air blast and temperature.

"(8) When using the same coal as on gas-producers, the flame is hotter, which allows the use of a greater percentage of scrap iron per ton of steel, thus reducing the consumption of high-priced pig-iron.

"(9) The finished steel is quieter in the moulds, as it is not over-oxidised, since the coal coming in direct contact with the bath has a greater reducing action. All gas-house troubles (cleaning fires, burning out flues, etc.) are eliminated, although the pulverising plant must be given attention as to dryness and fineness of coal.

"(10) Up to date, the refractory costs have been very much greater on the furnace using pulverised coal than on the gas-producer furnaces, and was almost twice as great a year or so ago, although the author believes that, on account of the steadily increasing development of the use of this fuel, refractory costs will be steadily decreased.

"The following table gives a comparison of the cost of fuel now used in open-hearth furnaces, showing that natural gas, where obtainable, is the cheapest fuel :—

Source of Heat.	Amount per Ton of Steel. 2000 lb.	Rate cost Fuel.	Cost of Fuel and Labour.	Fuel or Power Cost per Ton of Steel. 2000 lb.
		$	$	$
Natural gas	6000 cu. ft.	0·12 per 1000 cu. ft.	—	0·72
*Producer gas	510 lb. coal	3·40 per ton	3·93	1·00
*Producer gas	739 lb. coal	3·40 per ton	3·93	1·46
Fuel oil	40 gals	0·02 per gal.	—	0·80
Tar	30 gals.	0·025 per gal	—	1·00
Pulverised coal	500 lb. coal	3·40 per ton	3·90	0·975
Electricity	500 kw. hrs.	0·0075 per unit.	—	3·75

* The above table includes handling cost. The lower gas consumption for producer-gas is for hot metal, the higher gas consumption is for cold metal as determined at the Atlantic Steel Co.'s plant. Tar is a waste product at some plants, and has to be burned.

The output of one of the 50-ton pulverised coal-fired open-hearth furnaces at the Atlantic Steel Co.'s Works was 3219 tons (2000 lb.) of steel ingot in one month (31 days), with a coal consumption of 441 lb. per ton of steel.

It is very advisable to instal an open-hearth furnace specially designed for use with powdered coal, for then adequate provision can be made for the collection and removal of ash and ash slag. It is not an easy matter to convert a gas-fired open-

hearth furnace to pulverised coal firing; the passages through the chequers are usually too small, and it is often impossible to provide adequate chequer area when brickwork is rebuilt to allow for larger gas passages. Unless a very clean coal is available, the first few courses of the chequer work would become clogged up with ash. This would have to be removed, and some repairs effected after some 200 heats. The particular furnace illustrated in Fig. 178, designed by Fitch, metallurgical engineer of the Fuller Engineering Co., is fitted with removable ash bogies, and can

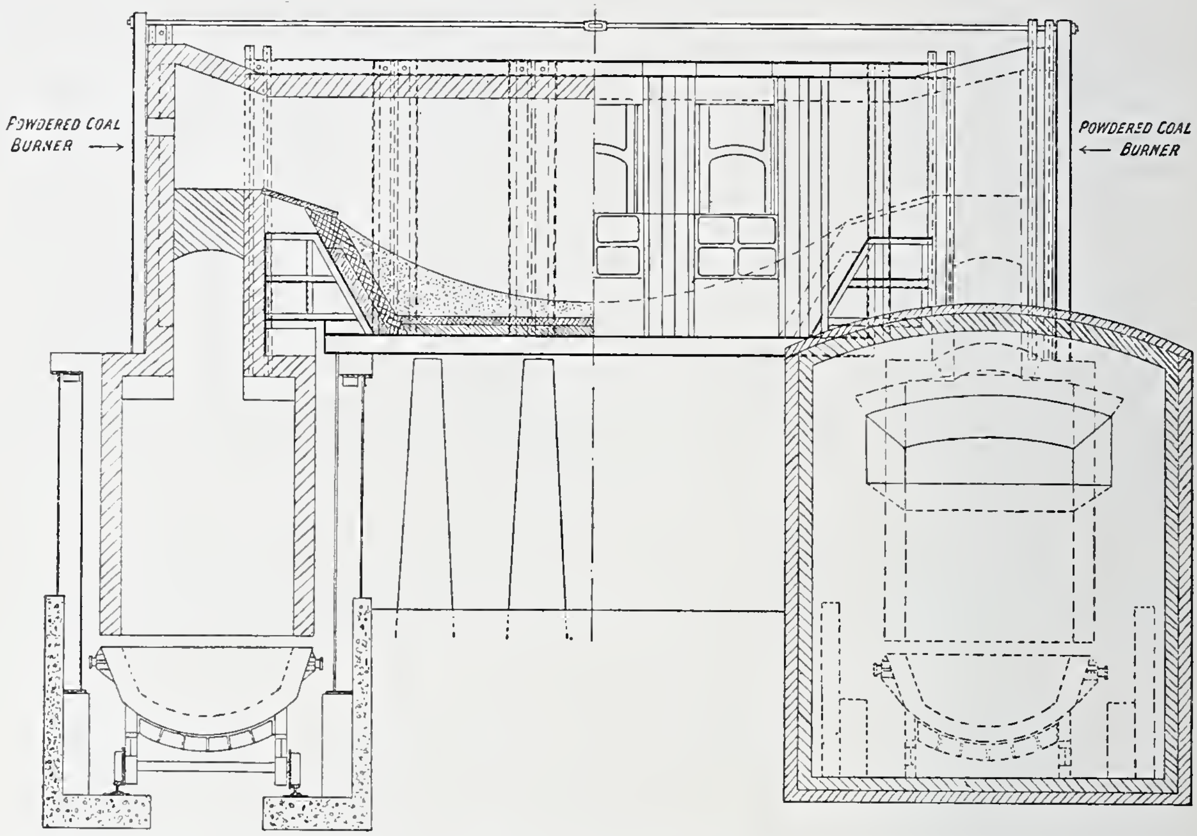


Fig. 178.—Arrangement of "Fitch" Design of Steel-melting Furnace with removable Slag Bogies.
(*The Fuller Engineering Company.*) (*The Fuller-Lehigh Company.*)

be run for 400 or 600 heats before it becomes necessary to clear out the chequers, thus equalling the life of chequers with producer gas firing.

The average life of chequers for the different systems of firing steel furnaces at one American works was found to be :—

With natural gas firing . . .	1000 heats
With producer gas firing . .	350 to 500 heats.
With oil firing	500 heats.
With powdered coal firing . .	225 to 250 heats (without slag bogies).

Of the ash introduced with the fuel, 50 % usually settles on the bath of metal, 30 % or 40 % collects in the removable slag bogies, and not more than 20 %

follows through to the chequers and flues leading to the waste heat boiler of the chimney stack.

The use of too coarsely pulverised fuel is a ready means of introducing chequer troubles, for it has been proved in one instance that all trouble resulting from the blockage of chequer passages was entirely removed when pulverised coal of a fineness of 95 % through the 200-mesh sieve was used, in place of the original coarser fuel of 95 % through the 100-mesh sieve.

Regeneration chambers so formed as to present vertical passages 12 in. square have been tried with success. This arrangement facilitates the extraction of the fine ash which has passed over the removable slag cars. Four 50-ton tilting furnaces have been operated on this principle for two years at one American works, with very good results.

The volume of chequer brickwork is usually based upon 70 cu. ft. per ton of steel melted; the temperature of gases passing into the chequers is generally between 1400° and 1880° F., and the stack temperatures after gases have passed through the waste heat boilers are in the neighbourhood of 250° F.

The four 50-ton tilting furnaces mentioned above are fitted with waste heat boilers, and the fuel consumption per ton of steel tapped is in the region of 700 lb. This figure is reduced to about 500 lb. of coal per ton of steel when credit is given for the steam raised in the waste heat boilers.

It is stated that one of these furnaces operated for seven months with 7 % ash coal before it was necessary to clean out the chequers, the slag cars being emptied of the fused ash slag once a week.

In many American steel works tar is considered to be the best fuel for firing the melting furnaces. It has a high calorific value, there is no ash, and the cost of the fuel-supply plant is small compared with the expensive producer-gas or pulverised-coal plant.

For small furnaces of 20 to 30 tons capacity the results obtainable with pulverised coal firing are usually as follows: Consumption is about 540 lb. per ton of steel ingots, as against 650 lb. for producer gas. Furnace output can also be increased, as evidenced in one instance where producer gas firing had been discarded, the output of steel from the same furnaces being 16,000 tons per month with pulverised coal firing, as against 10,000 to 11,000 tons when furnaces were producer gas fired.

In a battery of four furnaces, each of 28 tons capacity, the recorded fuel consumption with pulverised coal was as low as 500 lb., whereas 800 lb. of similar quality coal was previously used. Users have also stated that with pulverised coal firing there is no necessity to stop melting in order to burn out the flues, a necessary operation every three weeks with producer gas. With pulverised coal, therefore, the furnaces can be run continuously for upwards of 150 heats. In another instance, where fourteen 16-ton steel-melting furnaces were to be installed, the cost of pulverised coal plant was 60 % less than the cost of producer plant.

For melting steel in the open-hearth furnace, it is desirable to project the flame on to the centre of the bath, so that at each reversal the one or other end receives the greater intensity of heat. The distance from the burner inlet to the point where the flame impinges on the bath of metal should be about 15 to 20 ft. Burners are,

therefore, generally operated with high- and low-pressure air, and are made with swivel joints, so that the flame can be projected in the direction required.

Special Burners for Steel-Melting Furnaces.

The usual type of burner is shown in Fig. 145. Fig. 146 shows a burner for working with compressed air only; the coal dust in this case is syphoned out of the fuel chamber. Descriptions of these burners are given in Chapter XII.

The control of the flame direction by means of the swivel joint is decidedly beneficial, for it permits the flame to be impinged upon any part of the metal bath required, and prevents overheating of the roof or side walls, sometimes a serious matter when producer gas ports become worn out of shape. There is, of course, no wearing away of fuel entry ports when pulverised coal is used.

Puddling Furnaces.

Perhaps the greatest economy attending the application of fuel in pulverised form is in connection with its use for firing puddling furnaces of suitable shape and capacity. Not only is considerable economy effected in the consumption of fuel, but there is also increased output from the furnaces, and, in particular, smokeless operation of the plant. (See Fig. 180.) The last-mentioned point will be appreciated by all who reside near hand-fired puddled iron furnaces, the vicinity of which is smothered in rolling clouds of black smoke.

In 1918, the author inspected a large installation of furnaces in America, which had been converted from hand firing to powdered coal firing in 1903, and so operated from that year to the date of his visit. Of recent years also other plants have changed over to pulverised coal firing, and the results have been so favourable that this system will probably become standard practice in America. It was mainly due to a period of coal shortage during the War that investigations were made which revealed the enormous wastage that was going on daily. Every attention was then being given to fuel economy in industry, and the particular application of powdered coal to puddling furnaces has led to some very remarkable savings. Thus, for example, on hand-fired puddling furnaces, in certain instances, from 3000 to 3300 lb. of coal were used per short ton (2000 lb.) of iron produced, and after conversion to powdered coal firing the fuel consumption was reduced to 1450 lb. with cold air blast, and to 1150 lb. with air pre-heated to 500° F. An average saving of well over 50 % in fuel consumption has been the general result of applying coal in this manner. But this is by no means the only advantage gained from the change. With powdered coal firing, the amount of excess air entering the combustion chamber with the coal dust is practically constant at 20 %, whereas with hand firing appreciably more than 100 % is sometimes introduced. The difference in temperature with 20 % excess air and 100 % is very marked. In the former case the furnace temperature would be 1850° C., and in the latter 1200° C. The volume of gases passing through the furnace is appreciably less with powdered coal than with hand- or stoker-firing, thus making it possible to retain the hot gases for a longer period in the furnace, and, consequently, to extract a greater amount of heat therefrom during the passage of the gases over the hearth. Such conditions result in quicker heats, and, to quote

actual American results once more, 5 heats are obtainable per unit of time where previously 4 heats was the maximum.

The absolute regularity of firing conditions and the perfect control of the coal dust and air mixture show, by actual waste gas tests, that the percentage of CO_2 in powdered-coal-fired furnaces is considerably higher than in hand-fired furnaces, average readings recording 14 % as against 6 %. Free oxygen, which is required in the puddling process for getting rid of the carbon in the iron, is also appreciably greater, whilst there is an entire absence of CO, which, in hand-fired furnaces, is formed in considerable quantities, averaging 10 %; and every cubic foot of unburned CO in the waste gases, as they leave the furnace stack after passing through a waste heat boiler, means a loss of about 178 B.Th.U.

Some gas analysis records for a complete cycle of operations in a puddling furnace for hand and pulverised coal firing are given in Fig. 179. These charts were specially made to find out from actual gas analysis the precise advantages over hand firing which can be attributed to pulverised coal firing.

The first trials on puddling furnaces in England were made at the works of the Shelton Iron, Steel and Coal Co.; the general conclusions established were to the effect that :—

There was no difficulty in obtaining the required temperature, and from a cold start the furnace could be brought up to heat in $1\frac{1}{2}$ hours, as against 3 to 4 hours when hand-fired; there was little wear of refractory brickwork after the proper position for the burner setting had been found; fuel consumption was 30 % less than for hand firing and the furnace output was considerably increased; there would be no reduction in quantity of steam raised in a waste heat boiler, for, whereas fuel consumption was less, ruling temperatures were higher and waste gases cleaner; the man whose duty it had been to attend to hand firing could help in the more profitable occupation of handling the increased output of the furnace. Upon the estimated capital outlay for a comprehensive plant the net total savings would show a return in profits equal to about 20 %.

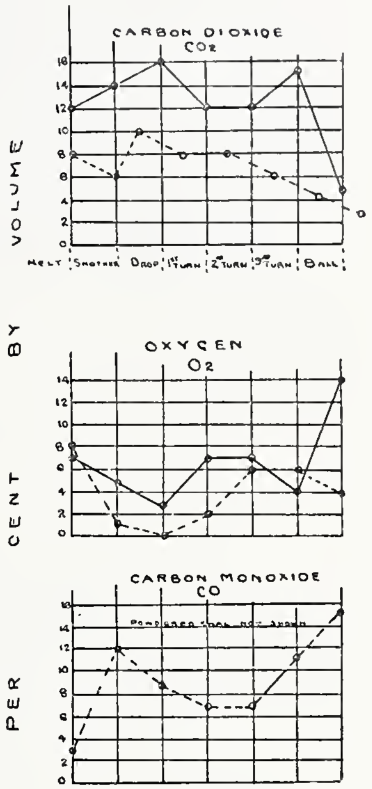


Fig. 179.—Curves showing Flue Gas Analysis for Hand Fired and Pulverised Coal Fired Puddled Iron Furnaces.

Pulverised Coal Firing ——
Hand Firing — — — — —

Sheet and Pair Furnaces.

Success has attended the application of pulverised coal firing to sheet and pair furnaces, and for this purpose it is advisable to obtain coal low in ash. Fuel for sheet and pair furnaces should certainly not contain more than 15 % ash, although fuel containing 25 % of ash has been used in certain cases. It is essential also to pulverise the coal to a fine degree, in order that as much as possible of the ash may

be carried in suspension right through the heating chambers to the chimney stack, without heavy settlement occurring upon the plates. A light dusting of fine ash appears to be beneficial, as stated below.

In sheet and pair furnaces it is generally found that a small quantity of the ash may form into a sticky mass at the burner inlet, whence it is removed by means of scrapers. The bulk of the ash remains unfused and passes into the flue or escapes at the furnace door, and a suction dust-collecting system should be provided for the withdrawal of dust as it emerges.

In the subsequent annealing of the plates the ash remains in the form of fine powder, which settles over the boxes, on the floor and in the flues. Its removal therefrom is an easy matter, and, moreover, the ash from the powdered coal protects the welded annealing boxes, from which double the life is obtainable as with hand firing or producer gas firing.

In no other specific applications is opinion so unanimously in favour of powdered coal firing as that expressed in relation to sheet and pair furnaces and annealing furnaces, and for this reason pulverised coal is being used as the medium for heating the furnaces in some of the largest sheet-rolling mills in America. The extensive developments in this particular direction have been closely followed by J. G. Coutant in connection with a number of Quigley pulverised coal plants installed for this purpose, and some of the data obtained by him is incorporated in the following notes on this subject.

In the manufacture of heavy steel products the temperatures to which the metal must be heated for the various processes are comparatively high, and permit of considerable latitude, but in the sheet-steel industry the temperature for rolling must be exact. At the sheet-rolling plants equipped during recent years in America: the Inland Steel Co.; the Falcon Steel Co.; Follansbee Bros.; the Mansfield Sheet and Tin Plate Co.; the Otis Steel Co., etc., firing the sheet and pair furnaces with pulverised fuel has been adopted as a means of insuring uniform temperatures in the furnaces and of preventing the oxidation of the metal. Fig. 181 illustrates the Quigley system at the Otis Steel Co.'s works, as applied to double chamber "Allis" pair furnaces.

Because of the ease with which uniform temperature can be maintained with pulverised coal firing, both the output of furnaces and quantity of sheets rolled have been greatly increased. From furnaces previously hand fired, the production per shift or crew was 0·7 to 0·9 ton (2000 lb. ton) of sheets; from the same furnaces fired with pulverised coal the average production was increased to 1·5 tons. This increase is accounted for chiefly by the fact that the mill operator is not required to adjust the speed of rolling to accommodate sheets at varying degrees of temperature. This result can be better realised by considering what takes place when metal bars or sheets are not always heated to the uniform temperature required. Suppose, for instance, that a bar from a pair furnace is a little cold for the first pass in the mill. The scale on the bar will not lift, and this scale, therefore, rolls into the sheets, making rough surfaces and causing them to stick together when they are later treated in packs. Close observation at one works confirmed the fact that powdered coal firing for the sheet and pair furnaces reduces stickers by 60 % to 75 %. Some-

FIG. 180.—VIEW OF LARGE ROLLING MILLS IN FULL OPERATION, SHOWING SMOKELESS CHIMNEYS OF PUDDLING FURNACES.

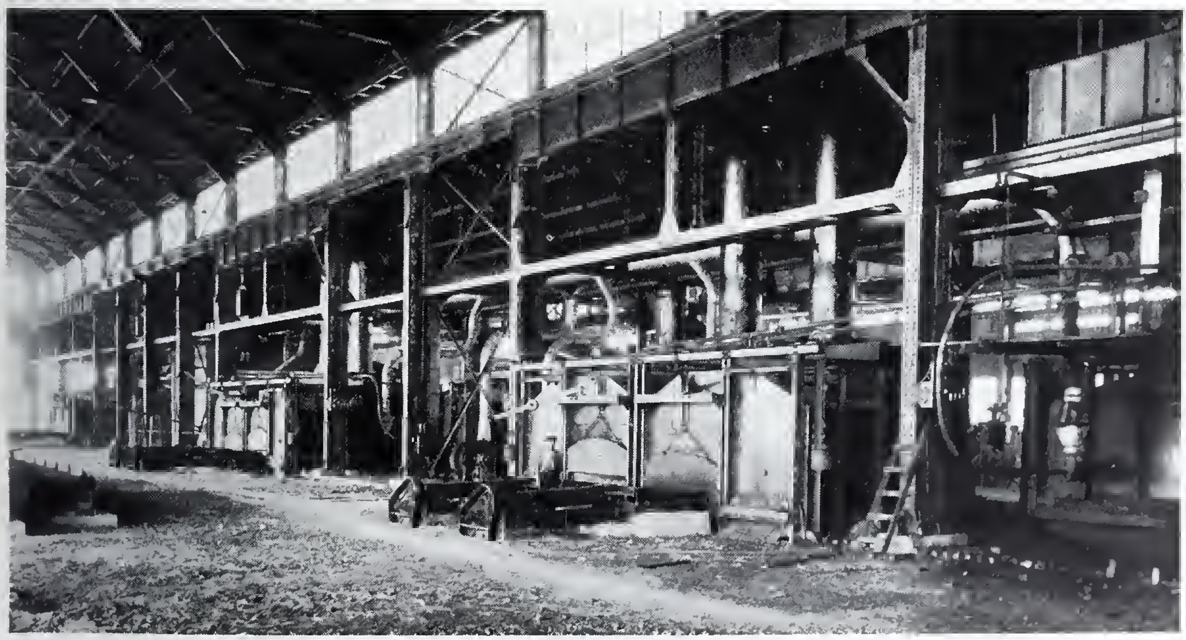


FIG. 181.—PULVERISED COAL FIRED CONTINUOUS PAIR FURNACES AT OTIS STEEL CO.'S WORKS.

Quigley Fuel Systems, Inc.]

[*To face p.* 318.

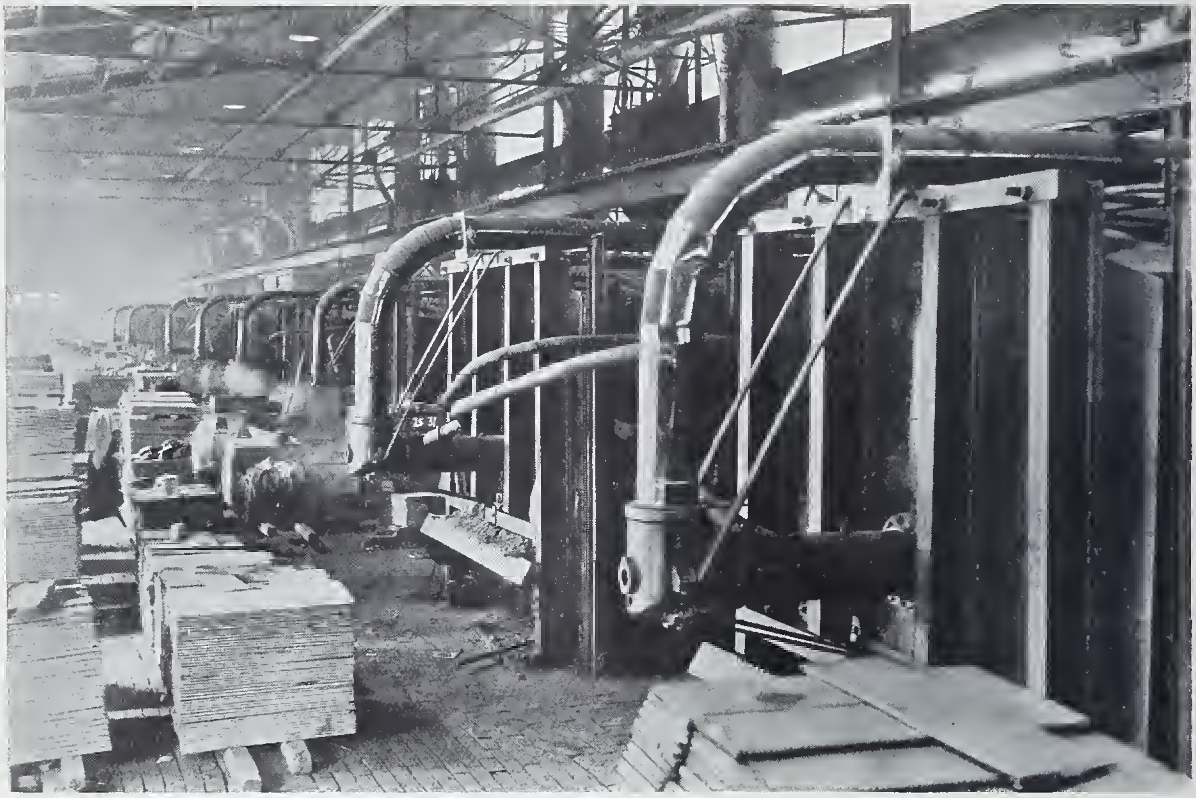


Fig. 182.—Quigley Burners at Rear of Eight Double-Chamber Sheet and Pair Furnaces.

The Quigley Fuel Systems, Inc.]

Fig. 183.—The Quigley System as applied to Annealing Furnaces at Otis Steel Co's Works.

The Quigley Fuel Systems, Inc.]

times a whole turn was run without a single "sticker," and the men liked the system on this account, for their output per shift was much increased, and their wages depended upon the output of sound sheet.

Owing to the perfect reducing atmosphere in the furnaces, it is necessary to polish the rolls only once every turn; previously it was often necessary to do this after every heat.

If, instead of a bar coming cold from the pair furnace, it is too hot, the conditions for rolling will be still worse. The large sheet rolls will then get hotter than the mill operator anticipates, and will expand to an extent which will throw out the line of contact between them. The bar, moreover, being too hot, it will likewise be too soft, and will not spring the roll to the required degree. The consequence, under these conditions, is that the finished sheet will be produced with a round end, which shows that the sheet is thinner in the centre than on the sides, while, in the case of a "cold" bar that is rolled at too low a temperature, the sheet will have long ends on each side. Round end sheets generally indicate that the rolls are "full," and long ends on each side that the rolls are not properly filled.

Now consider the effect of these "round"- and "long"-ended sheets in the sheet furnace. When the round-ended sheet is placed on top of a long-ended sheet and the two are heated and put through the rolls together, the pack will run off at the back end, that is, the sheets will spread from one another on the back end of the pack, due to the uneven drawing of the metal. The mill operator, even by exercising the greatest care and skill in adjusting the draw screws, cannot prevent this. Scale produced by excessive heating will lift in spots, and will sink again into the sheets, causing the pack to stick together in patches, so that the sheets cannot be prised apart without tearing. Everyone familiar with sheet rolling realises that the rolls must be kept at the proper shape to roll thin sheets successfully.

A mill operator must, subconsciously, count on a certain spring to the strand of rolls, and, by trial and error, find the proper temperature at which the sheets should be rolled to suit the shape of his rolls. He will watch carefully the size of the ends on each side of the sheet, to tell him whether the space between the rolls is evenly filled. He knows that if he rolls too fast, not allowing enough time between passes, his rolls will expand and make plates of uneven thickness. Neither must he roll too slow. He must constantly watch and guard against such things as cold draughts of air blowing on the rolls—in fact, anything that affects the temperature of the roll. By maintaining the heating furnaces at uniform temperatures, much of the operator's anxiety and continuous adjustments of rolls are eliminated.

The proved advantages of powdered fuel firing in the sheet mill industry are that there is considerably less roll breakage with powdered coal than with other fuels, and that the rolls may be made larger in diameter, thus increasing the tonnage that can be turned out. In sheet furnaces, such as shown in Fig. 182 (eight double-chamber sheet furnaces together with the pair furnace), sheets and tin plates have been produced with 104 kilos (230 lb.) of pulverised fuel per ton (2240 lb.) of sheet produced.

One of the remarkable features of pulverised coal firing is the increase in the number of bars rolled per hour due to the time saved because the metal is thoroughly

and uniformly heated. Fewer passes are required for the reduction in thickness of metal rolled with one heating, for the operator will pass the pairs through the rolls twice, instead of three times, as would be necessary with other fuel. When rolling the sheets, the operator will pass the sheets through the rolls eight times instead of ten times. This reduction in the number of passes for the sheet and pair operations considerably increases the output of the rolling mills over a given period.

The very small excess of air used with pulverised fuel firing results in a considerable reduction of scaling loss, and, as scale is responsible for sheets sticking together when rolled in packs, this trouble is practically eliminated. The ash or dust settlement upon the sheets while they are being heated is far from being detrimental in any way, for it has been found and proved in practice to be beneficial to smooth rolling and polishing of the surfaces of the metal sheets.

In the production of sheets there is a further beneficial result which follows upon the use of pulverised fuel for firing the annealing furnaces.

The life of the annealing box has always been a serious question. Here also, owing to the small quantity of excess air, there is very little oxidation of the boxes; the comparative life of bottoms and tops of the annealing boxes per ton of sheets annealed for producer gas firing and pulverised coal firing is on record, and is in proportion to the following actual costs per ton of sheets annealed: pulverised fuel, 9 cents; producer gas fired, 27 cents for the bottoms of boxes, and $13\frac{1}{2}$ cents for the tops of boxes.

Fig. 183 shows the annealing furnace plant consisting of seven double annealing furnaces, each holding 80 tons of sheets, at the Otis Steel Co.'s works.

The foregoing remarks were confirmed at the Standard Tin Plate Works, Canonsburg, Pa., U.S.A., where a Holbeck plant had been in operation for some time when the author visited the works in 1918. It was stated by the management that the use of pulverised coal was most successful in the following particulars:—

In the Hot Mill Department:

(1) Steel, after being rolled, is softer than with gas.
(2) Steel opens more readily; therefore reducing stickers approximately 60 %.
(3) Reduces the necessity of polishing rolls over 75 %.

In the Annealing Department:

(1) Uniform temperature easily obtained.
(2) Reduces scaling upon annealing boxes by deposit of ash thereon.

In the Tinning Department:

The firing of the kettles with pulverised coal was just as uniform as with natural gas.

Excellent descriptions of two of the American sheet-rolling mills referred to above—the Falcon Steel Co., Niles, Ohio, and the Newport Rolling Mill Co.,

Newport, Ky.—are given respectively in *The Blast Furnace and Steel Plant* and *The Iron Age*. These refer to Quigley installations, and illustrations are given of the mills in full operation, but no smoke is visible at the furnace stacks.

At the former, and smaller, works, a 5-ton-per-hour mill plant delivers the pulverised coal by means of a five-ton-capacity compressed-air " blowing " system through 4-in. pipes to the receiving bins at the different departments, the aggregate length of transport line being 1700 ft. There are seven double-chamber sheet furnaces, and four double-chamber and one single-chamber pair furnaces. In the annealing department there are one continuous Costello furnace, two double box double-chamber furnaces, and one blue annealing furnace. All furnaces, including the three galvanising pots and grease kettle, are pulverised coal fired, and are typical of the types of furnaces now so generally heated in this manner in America.

The furnace plant at the Newport Rolling Mills is more extensive, the capacity of the coal-milling plant being 12 to 15 tons per hour. Results obtained at the latter works show that the slab-heating furnace consumes 180 lb. of coal per ton (2000 lb.) of product, the sheet and pair furnaces 275 lb. per ton (2000 lb.) of sheets rolled, the annealing furnaces 170 lb. per ton (2000 lb.) of sheets annealed, the galvanising pots 110 lb. of coal per average ton (2000 lb.) of sheets galvanised.

As against hand firing, when 650 lb. of coal were used per ton of sheets rolled, fuel consumption was reduced to 300 lb. of coal after the furnaces had been arranged for pulverised coal firing at one of the American works, and at another from 450 lb. to 290 lb.

The time taken to bring annealing furnaces up to temperature is much less with pulverised coal than with producer gas firing, recorded results being 12 to 15 hours for the former, as against 17 to 24 hours for the latter.

From the costing department at a rolling mill, the following comparison has been obtained as to the cost of running annealing furnaces per month with natural gas, fuel oil and pulverised coal.

Natural gas, 14,000,000 cu. ft. at 27 cents	\$3,780·00
Fuel oil, 105,000 gallons at 8 cents	\$8,400·00
Powdered coal, 525 tons at \$5·00	\$2,625·00

The cost per ton for powdered coal includes all charges, except depreciation and interest on capital.

Readers will find much information upon the subject of hot rolling in sheet mills in the *Revue Universelle des Mines*, July and August 1919, in an article entitled " Les Théories du Laminage à chaud," by P. Maringer.

It will be seen that very considerable profit can be realised from the use of pulverised coal in a sheet-rolling mill. An estimate as to the profits to be gained thereby in the three main departments of such a works, viz. the rolling mills, the annealing shops, and the galvanising department, has been based upon actual results, and is as follows :—

Comparison of Cost for Operation of Furnace Plant at a Sheet Mill as designed by the Quigley Furnace Specialities Co.

SHEET-ROLLING DEPARTMENT :

Hand Firing

Coal. 130,000 tons of sheets @ 534 lb. per ton = 34,650 tons @ \$4·00		\$138,600·00
Labour. 34,650 tons coal @ 60 c. per ton for distributing coal and disposal of ashes		20,790·00
Total Annual Cost :		\$159,390·00

Pulverised Coal Firing

Coal. 130,000 tons of sheets @ 325 lb. per ton = 21,100 tons @ \$4·58	\$96,750·00	
Labour. For distribution, etc.	672·00	
Power. For controllers and fans 277,500 kw. hrs. @ 5 c.	1,387·50	
Fixed Charges. Interest, depreciation and repairs on \$46,869·00—the cost of pulverised coal plant for this department—@ 14 %	6,570·00	\$105,379·50
TOTAL ANNUAL SAVING :		\$54,010·50

GALVANISING DEPARTMENT :

Hand Firing

Coal. 84,000 tons of sheets @ 175 lb. per ton = 7,350 tons @ \$4·00 .	\$29,400·00
Labour. 7,350 tons coal @ 60 c. per ton for distributing coal and disposal of ashes	4,410·00
Total Annual Cost :	\$33,810·00

Pulverised Coal Firing

Coal. 84,000 tons of sheet @ 100 lb.	\$19,236·00	
Labour. For distribution, etc.	672·00	
Power. For controllers and fans 193,500 kw. hrs. @ 5 c.	957·50	
Fixed Charges. Interest, depreciation, and repairs on \$21,659·00—the cost of pulverised coal plant for this department—@ 14 %	3,035·00	\$23,900·50
TOTAL ANNUAL SAVING :		\$9,909·50

ANNEALING DEPARTMENT :

Producer Gas Firing

Coal. 130,000 tons of sheets @ 380 lb. per ton = 24,700 tons @ $4·00	$98,800·00
Labour. 24,700 tons coal @ 50 c. per ton for gasification of coal and disposal of ashes	12,350·00
Fixed Charges. Interest, depreciation and repairs on $100,000·00 producer installation @ 14 %	14,000·00
Total Annual Cost :	$125,150·00

Pulverised Coal Firing

Coal. 130,000 tons of sheets @ 200 lb. per ton = 13,000 tons @ $4·58	$59,540·00	
Labour. For distribution, etc.	672·00	
Power. For controllers and fans 107,000 kw. hrs. @ 5 c.	535·00	
Fixed Charges. Interest, depreciation and repairs on $37,395·00—the cost of pulverised coal plant for this department—@ 14 %	5,225·00	$65,972·00
TOTAL ANNUAL SAVING :		$59,178·00

Cost of plant for the three departments = $105,913.
Total savings per annum for the three departments = $123,098.

Malleable Iron-Melting Furnaces.

One of the latest and most successful applications of pulverised coal firing is to malleable iron furnaces.

In America there are approximately 270 malleable casting plants, and it is expected that pulverised coal firing will be exclusively adopted, as a consequence of the success obtained.

The presence of ash in the melting furnaces does not affect the quality of the metal melted. A certain percentage melts and falls upon the slag, and is taken out of the furnace when the metal is skimmed. Accumulation of slag in the pocket of the furnace between the bridge wall and the damper is removed every day. Coal containing about 8 % ash is used, and the amount of ash in the form of slag removed from the furnace pocket is equal to about 10 % of the ash contained in the coal.

At the most recent installation in America, at a works where some 24,000 tons of journal boxes are made per annum, the castings having to stand a tensile test of about 50,000 lb. per sq. in. with an elongation of 0·18, five melting furnaces are used, four having originally a capacity of 20 tons each, and one of 13 tons, all in the first instance hand fired.

The average charge consisted of 50 % pig iron, 45 % scrap (hard and soft), and the balance of 5 % steel scrap. The quantity charged was 20 tons, allowing 10 % melting loss under hand-firing conditions.

When hand fired, two heats were run per 24 hours, making a total of 160 tons of metal tapped for the four working furnaces. The melting ratio then obtained was $2\frac{1}{2}$ lb. iron per lb. of coal over the 2-heat period.

The melting furnaces were changed over to pulverised coal firing by covering up the grate bars, and removing the bridge wall next to the grate bars, thus making this area serve as an extension of the bath, and thereby increasing the tonnage of the furnace by about $33\frac{1}{3}$ %. The capacity of each furnace is now 30 tons of metal per heat, and even 36 tons of metal have been run down at a single melt. The output of four furnaces is, therefore, 240 tons for 2 heats per furnace per day, and the melting ratio is $3\frac{1}{2}$ lb. of metal per lb. of coal.

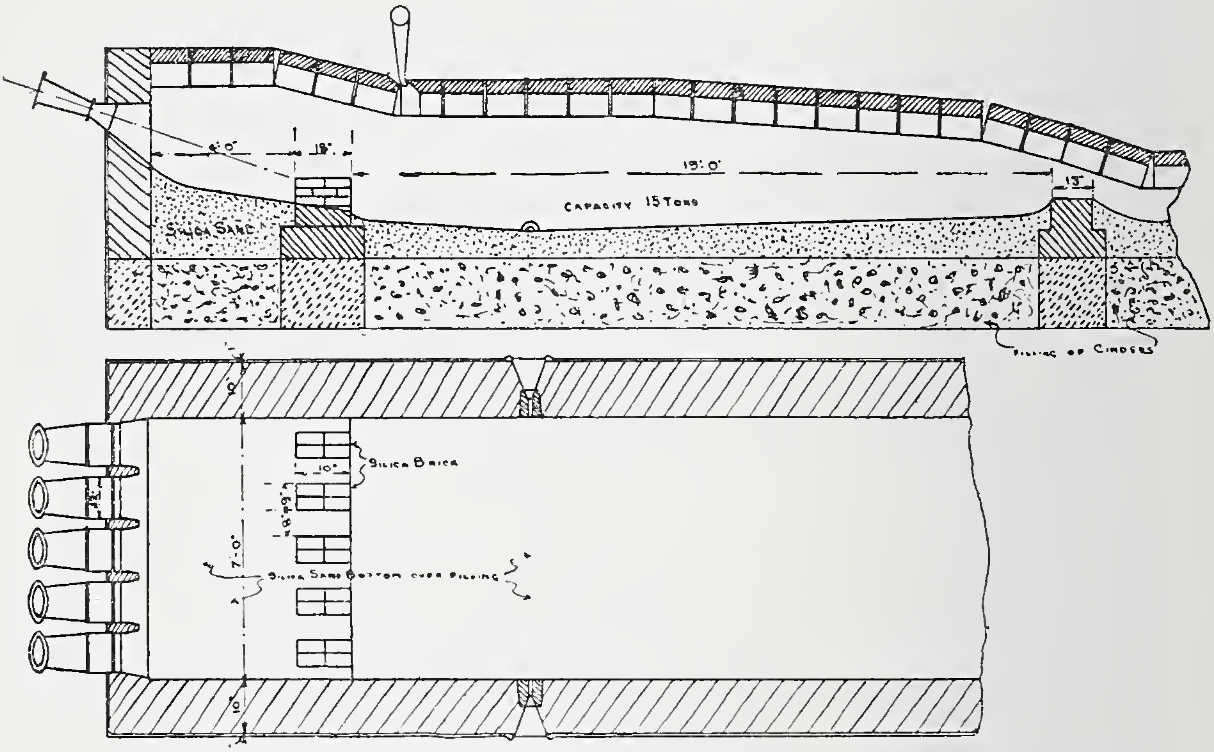


Fig. 184.—Arrangement of Pulverised Coal Fired Malleable Iron-melting Furnace. (*Joseph Harrington.*)

All the labour required for hand firing (two men) has been dispensed with.

Run-of-mine slack coal is used in pulverised form to serve both the melting and annealing furnaces, the latter showing a coal consumption of 1 lb. of coal burned per 3 lb. of metal annealed.

Figs. 184 and 185 show the method of applying powdered coal to a malleable iron-melting furnace, in which temperatures between 3000° F. (1650° C.) and 3220° F. (1770° C.) can be obtained with air at 60° F. (15° C.).

Melting conditions are under perfect control, and at this degree of heat there is of necessity little free oxygen present, so that the burning out of valuable elements, such as carbon and silicon, is avoided, and melting takes place with a very low loss.

By the use of powdered coal the flame can be directed on to the bath of metal;

thus it becomes possible to dispense with the " top air " jets usually provided on hand-fired furnaces for the purpose of forcing the hot gases away from the roof brickwork and on to the metal bath.

Mr. Joseph Harrington (in *The Foundry*, October 1916 and December 1918) has given a concise explanation of the radiant heat effect of minute incandescent carbon particles, the benefit of which is fully realised, when malleable iron furnaces are fired with pulverised fuel. When comparing older methods with that of coal-dust firing, he remarks that in ordinary practice, air, usually known as top air, is introduced into the furnace from above. This supplies the necessary oxygen for the complete burning of the hydrocarbon gases evolved in the fire-box, and also serves to force the hot, burning gases down on to the metal bath.

It has been customary to apply this secondary air by means of from four to six nozzles, spaced across the top of the furnace and slanting downward towards the metal bath. It is almost obvious, however, that 2-in. jets of air spaced 15 or 20 in. apart will not have a character other than that of jets.

For pulverised coal firing the nozzles are placed in such a manner that the fuel jet itself is directed downward toward the hearth. The velocity of the jet being controllable, the flame can be made practically of any length desired. By using a high-velocity jet it would be possible to cause the flame itself directly to strike the liquid iron and spread out in a continuous sheet over the surface of the metal, or to mingle intimately with the pile of iron on the hearth. On the other hand, it is equally possible to decrease the velocity of the jet to a point where it reaches the right part of the furnace close to the metal, and thereupon loses the velocity acquired at the nozzles and becomes a floating mass of gas moving with relative slowness through the furnace. To hold the sheet of slowly moving but very intensely heated gas near the surface of the metal, a relatively thin, continuous sheet of air can be introduced in the same place at which the top air nozzles ordinarily are located.

In the malleable melting furnace, after the pile has begun to subside, there is little or no tendency for the gases to mix, and the effect of the air curtain described is, therefore, to cause a stratification of the gases in the furnace. The hottest gases are held down in the furnaee in direct contact with the metal bath. At the same time there is a certain protection to the roof of the furnace caused by the layer or stratum of air in immediate contact therewith. With a highly preheated air under control, the incandescent, pulverised coal flame can be made to skim along the surface of the bath in direct physical contact with it, and in the very best position to impart to it the maximum amount of heat.

The beneficial result obtainable from the better contact of gas and metal, and the utilisation of the radiant heat, is a quicker melt with less burning out of the desirable elements of silicon, manganese, and carbon.

With pulverised coal it is possible to get an incandescent front within a few minutes of the time of starting, even though the furnace be perfectly cold at first. The high temperature is maintained consistently until tapping is begun. It is inevitable that the iron should melt quicker under these conditions, and just as inevitable that the losses of valuable ingredients should be reduced. Slag troubles do not occur, because the ash liquefies and runs down on to the metal bath, from which it is skimmed periodically with the rest of the slag. The conservation of the

carbon, etc., has a directly favourable influence on the amount of high-grade iron to be charged, and a definite saving, variously estimated from 2 to 5 %, is the result.

The estimated net savings introduced by the application of pulverised coal firing in the malleable iron foundry have been calculated by the Grindle Fuel Equipment Co. from practical results, and the following comparison between the costs of hand firing, oil firing and pulverised coal firing is based upon this information. It is assumed that the plant consists of two 10-ton air furnaces melting two 10-ton heats per day (2000 lb. per ton).

HAND FIRING FOR 20 TONS OF METAL.

Item.	Amount.	Price.	Total Operating Cost.
1. Fuel, 47%	18,800 lb.	\$7·00	\$65·00
2. Coal preparation conveying and power	18,800 lb.	0·20	1·88
3. Pig iron, 50%	20,000 lb.	27·00	—
4. Hard remelt, 40%	16,000 lb.	20·00	—
5. Malleable scrap, 10%	4,000 lb.	18·00	—
6. Kindling	112 lb.	0·25 cwt.	0·25
7. Grate bars	56 lb	6·00 cwt.	3·00
8. Power for combustion air	—	—	—
9. Firing labour	24 man hrs.	0·55	13·20
10. Ash handling	—	—	0·88
11. Total daily cost for 20 tons of metal			\$84·21
12. Furnace loss, 6%	2,400 lb.	\$29·012	34·81
	Overall total cost		\$119·02 for 20 tons of metal.
	,, ,,		\$5·95 per ton.

OIL FIRING FOR 20 TONS OF METAL.

Item.	Amount.	Price.	Total Operating Cost.
1. Fuel, 75 gals. per ton	1,500 gals.	\$0·06	\$90·00
2. Coal preparation conveying and power	—	—	—
3. Pig iron, 53%	21,200	27·00	—
4. Hard remelt, 40%	16,000	20·00	—
5. Malleable scrap, 7%	2,800	18·00	—
6. Kindling	—	—	—
7. Grate bars	—	—	—
8. Power for combustion air 13 h.p., 10 hrs.	97 kw. hrs.	0·015 kw.	1·45
9. Firing labour	12 man hrs.	0·55 hr.	6·60
10. Ash handling	—	—	—
11. Total daily cost for 20 tons of metal			\$98·05
12. Furnace loss, 7%	2,800 lb.	\$29·154	40·81
	Overall total cost		\$138·86 for 20 tons of metal.
	,, ,,		\$6·94 per ton.

Pulverised Coal Firing for 20 Tons of Metal.

Item.	Amount.	Price.	Total Operating Cost.
1. Fuel, 35%	14,000 lb.	$6·00	$42·00
2. Coal preparation conveying and power	14,000 lb.	2·04	14·28
3. Pig iron, 40%	16,000 lb.	—	—
4. Hard remelt, 40%	16,000 lb.	—	—
5. Malleable scrap, 20%	8,000 lb.	—	—
6. Kindling	—	—	—
7. Grate bars	—	—	—
8. Power for combustion air 13 h.p., 10 hrs.	97 kw. hrs.	0·015 kw.	1·45
9. Firing labour	12 man hrs.	0·55 hr.	6·60
10. Ash handling	—	—	—
11. Total daily cost for 20 tons of metal	—	—	$64·33
12. Furnace loss, 4%	1,600 lb.	$26·30	21·04
	Overall total cost		$85·37 for 20 tons of metal.
	,, ,,		$4·27 per ton.

Comparison between Total Overall Costs per ton of Metal Melted

Hand firing	$5·95
Oil firing	$6·94
Pulverised coal firing	$4·27

Pulverised coal firing :

Saving over hand firing—$1·68 per ton of metal melted.
Saving over oil firing— $2·67 ,, ,, ,,

In addition to the items enumerated in money values above, there are also the savings to be introduced due to the different composition of the charge, also small savings in favour of pulverised fuel for skimming bars, slag handling, repairs to brickwork, etc. These smaller considerations have been omitted from the above calculations.

The calculations show that for an expenditure of $75,000, the total cost of pulverised coal plant for melting furnaces and annealing furnaces, for a melting capacity of 60 tons of metal per diem, the saving in money over hand firing on the melting furnaces alone would return a net profit of $30,240 per annum, and savings on annealing process would no doubt double this figure. In this estimate a provision of $2·00 for preparation cost and burning of pulverised coal has been allowed for these purposes and for depreciation.

Piling and Welding Furnaces.

The application of pulverised coal to recognised standard types of reheating furnace for billets, or bars or to faggotting, bushelling or piling furnaces presents no difficulty.

It is upon these types of furnaces that most of the original tests with pulverised coal firing were carried out, and the initial results obtained have been the means of greatly extending the use of pulverised fuel for metallurgical furnace heating. The Holbeck air and fuel mixture system as applied to a large billet heating furnace is shown in Fig. 187.

Fig. 170 shows a standard type of three-door heating furnace. Furnaces of this design are generally used in America for heating iron piles, faggots and slabs for rolling. A furnace of the type illustrated, taking a charge of 84 piles measuring 4″ × 4″ × 24″ for the making of pipe skelp, will be ready for drawing in about 50 minutes; the temperature of the furnace at the time of drawing the charge is 2560° F. (1400° C.).

In piling furnaces there appears to be no trouble introduced by reason of fused ash settling on the metal. Most of the liquid ash drops off the pile before the pile reaches the rolls, and that which still remains adhering to the metal flakes away during the first pass in the mill, and does not roll into the metal.

As in the case of puddling furnaces, the bulk of the ash is usually fused and collected in the combustion chamber, from which it is cleared away periodically by dropping the bars (usually the old firebars), which are covered with a bed of ash, on which the fused slag is deposited. Of the ash carried over into the heating chamber the greater portion will be fused, and is generally run off in a semi-liquid form from one corner of the hearth. Apart from a small quantity of ash slag which adheres to the pile, the remainder, in the form of fine dust, passes into the flues. The bottom of a piling or bushelling furnace is built with a slight slope to one corner, so that the fused ash can be run to one tap hole.

In a piling furnace, the coal consumption per ton (2240 lb.) of metal heated usually runs from 500 to 530 lb., and the amount in other furnaces, such as a bushelling furnace, about 450 to 500 lb.; a faggotting furnace, 530 lb.; a muck bar furnace, 700 lb.; a skelp heating furnace, 300 lb. of coal per ton of steel.

As against oil or natural gas firing, the average loss of metal when heating piles for rail rolling has been reduced from 5 % to 2 % when pulverised coal has been substituted.

Pulverised coal firing can be applied to certain types of bar or plate-welding furnaces, but exceptional care must be given to the manner in which the fuel is introduced. The coal should contain little ash. For tube strip welding there must be no slag which will prevent a perfect weld, and although furnaces were fired in this manner at an American works for many months, the occasional faulty welding experienced, due to the slag on the weld, was the ultimate cause of the abandoning of pulverised coal firing.

On the other hand, satisfactory results have already been established at a works in France with a double-chamber furnace fired by means of an Aero pulveriser. One chamber is utilised as the firing chamber, the other as the welding hearth, in which the high temperature required is maintained without deposit or slag upon the tube strips.

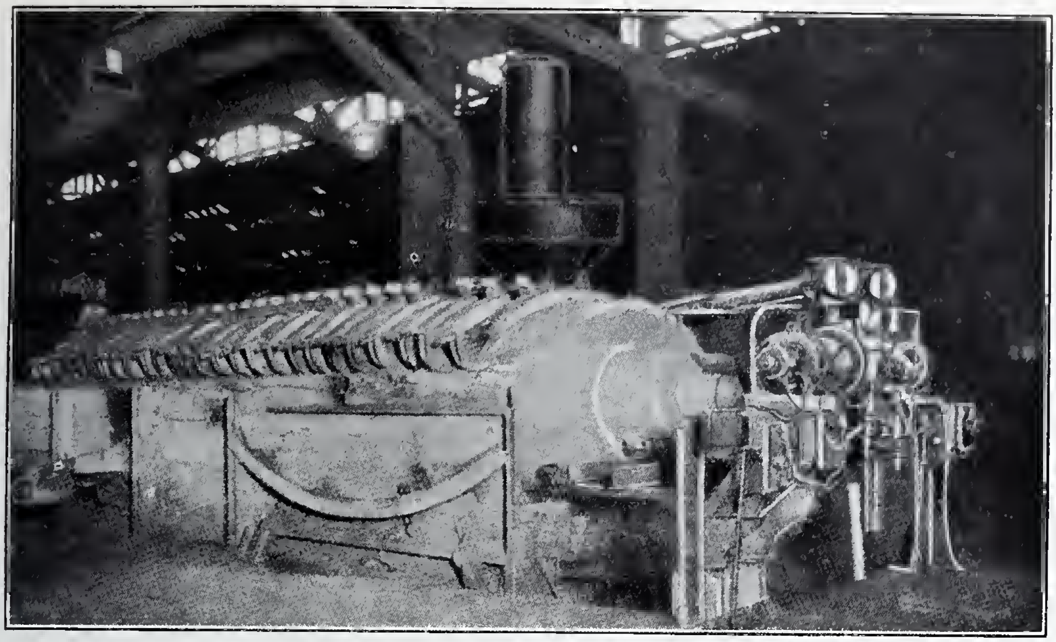


FIG. 185.—MALLEABLE IRON-MELTING FURNACE FITTED WITH SPECIAL FOGLER BURNERS.

FIG. 186.—THE FULLER SYSTEM AS APPLIED TO SHEET AND PAIR FURNACES AT NEWTON STEEL CO.'S WORKS, SHOWING AUXILIARY BURNERS FOR WASTE HEAT BOILERS.

The Fuller Engineering Co.] [*The Fuller Lehigh Co.*

[*To face p.* 328.

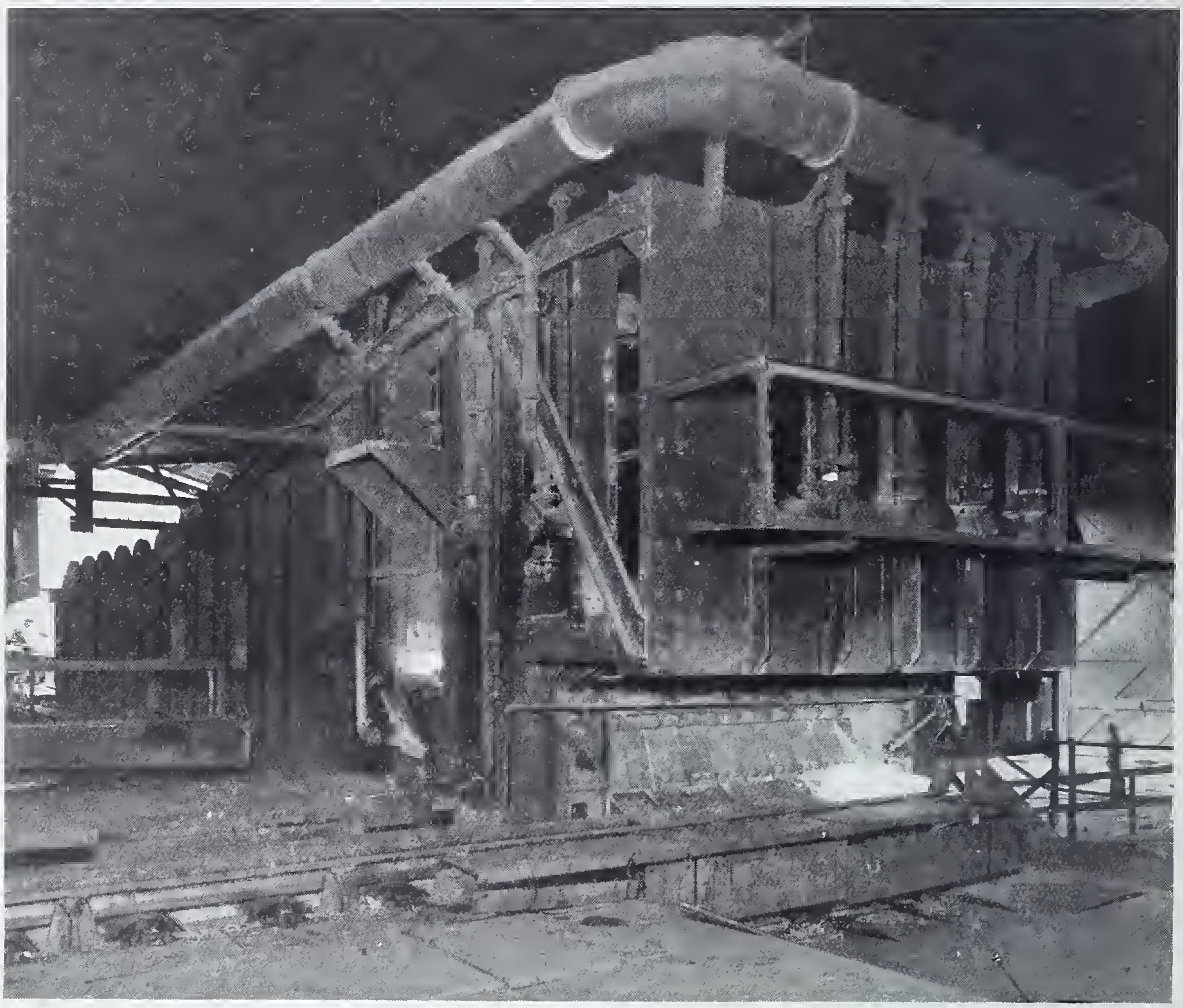


Fig. 187.—The Holbeck System as applied to Billet-heating Furnaces by the Bonnot Co. The Secondary Air Supply Main is above and behind the Fuel Supply Piping.

A. Holbeck.] [*The Bonnot Co.*

Heavy Forge Furnaces.

The use of pulverised coal for firing heavy forge furnaces can be accepted as another of the outstanding successful applications of this method of heating in the iron and steel industry. Little or no difficulty is generally presented by the ash in the fuel. The bulk of the ash is deposited in the actual heating chamber, only a small proportion finding its way into the flues and up the stack. The ash remaining in the furnace is run off in the form of slag, as in piling and bushelling furnaces.

In general, such applications have shown great advantages for nearly all heavy work, heated in furnaces that can be run at a very uniform temperature and in which the heat is evenly distributed.

The quality of the forgings made from billets heated in pulverised coal-fired furnaces is stated to be superior to gas or hand-firing practice. The operator of a powdered coal-fired furnace looks after the regulation of his own coal feeder and burner, and as there are no ashes to clear away, the service of the man whose whole time is given to the firing of a hand-fired furnace is not required.

The tonnage output of a forge furnace is considerably increased when pulverised fuel is used. In one case, two hand-fired heating furnaces were used in keeping one steam hammer going, but when these furnaces were changed over to pulverised coal firing, it was possible to keep the hammer up to its full output with only one heating furnace. As to economy in fuel, the amount of coal burned in the furnaces when hand fired was 265 lb. per ton of steel heated, and in pulverised form this figure was reduced to 150 lb. at the furnace. These particular furnaces were used for heating billets for heavy gun forgings.

Fig. 188 shows a range of heavy billet-heating furnaces at an American works where all the furnaces are fired with pulverised coal. The output of this forge plant is the largest in America, equal to about 60,000 tons of forgings per annum; individual forgings, propeller shafts, rising to a maximum weight of 45,000 lb.

Light Forge Furnaces.

An equal measure of success has not been realised with the firing of light forge furnaces with pulverised coal. The type of heating furnace for general use for this work is usually of simple construction, relatively small, and is not always provided with adequate flue and chimney. The result is that most of the fine ash and dust finds its way into the building.

Unless an efficient suction exhaust system is provided for drawing off the fine dust as it comes out of the furnace door, this will be deposited over the building and upon the machinery. In some light forge shops this has not only been a nuisance, but the bearings of running machinery have become severely worn away in a short space of time.

In several cases, pulverised coal firing for small forge furnaces has been discontinued because of the dust and nuisance and also because time was lost in getting the furnaces away in the morning. The cost of coal preparation was also found too expensive for this class of work.

For light forgings the amount of coal used in pulverised form per ton (2200 lb.) of steel heated is usually about 500–550 lb.

On account of ash deposit on metal heated and the formation of a hard slag thereon, pulverised coal has been discarded for heating metal for hot pressing.

In the case of wheel making, the settlement of ash upon the steel blanks affected the dies and matrices to such an extent that the accuracy of work produced was impaired.

In spite of these disadvantages, at a certain works visited, the administration had decided upon the building of a new pressed-steel shop in which all the furnaces were to be arranged for pulverised coal firing. The reason for this was that the foremen and men of other shops had so repeatedly sent in requests to have their furnaces converted to powdered coal firing, as against hand firing, that it was considered advisable to replenish the dies more often and to obtain the support of the men, in addition to the saving of about 20 % in coal over hand-firing practice.

As stated above, the chief objection to the use of pulverised coal for small furnaces is the difficulty experienced with fine abrasive dust emitted at the furnace doors. At the Lemoine works in Paris, there is perhaps one of the best examples of a well-designed plant for small furnaces. Some 72 furnaces used in the manufacture of springs are fired with pulverised coal, the full duty of the mill plant being 2 tons of coal per hour. The feature of the installation is the exceptionally well designed exhaust system for collecting and removing the waste gases and fine dust at the furnace doors.

Rivet-Heating Furnaces and Galvanising Kettles.

For the same reason pulverised coal firing is not very suitable for heating small rivet and bolt furnaces. Fuel consumption figures are, as a rule, unobtainable for the various types of small furnaces. For heating iron for making $\frac{5}{8}$ in. and $\frac{3}{4}$ in. stay bolts the fuel used is about 1800 lb. per ton (2000 lb.) of bolts made.

Pulverised coal firing can be successfully applied to galvanising and tinning kettles, Fig. 190. An even temperature as with oil or gas firing is readily obtainable. For such purposes and for other moderate or low-temperature work, the ash is not fused, but is deposited in the flues, and at the chimney base, and presents no difficulty in its removal.

Ore Roasting and Lime Calcination.

In the old original types of hand-fired roasting and smelting furnaces, about $3\frac{1}{4}$ tons of 11,500 B.Th.U. coal were used per ton of zinc ore roasted and smelted. The introduction of improved designs of furnaces, and the application of producer gas firing, has brought down the fuel consumption to about 1 ton of coal per ton of ore smelted under the latest and most up-to-date methods.

The application of pulverised coal firing has as yet been made only to the hand-fired designs of roasting and smelting furnaces, and this has reduced the fuel consumption from $3\frac{1}{4}$ to 2 tons of coal per ton of ore smelted. With improved types of roasting furnaces, designed for pulverised coal firing, and having regenerative chambers, it is presumed that the overall fuel consumption would be about equal to producer gas firing.

In one case of hand-fired zinc-copper ore reverberatory furnaces 40 to 50 tons

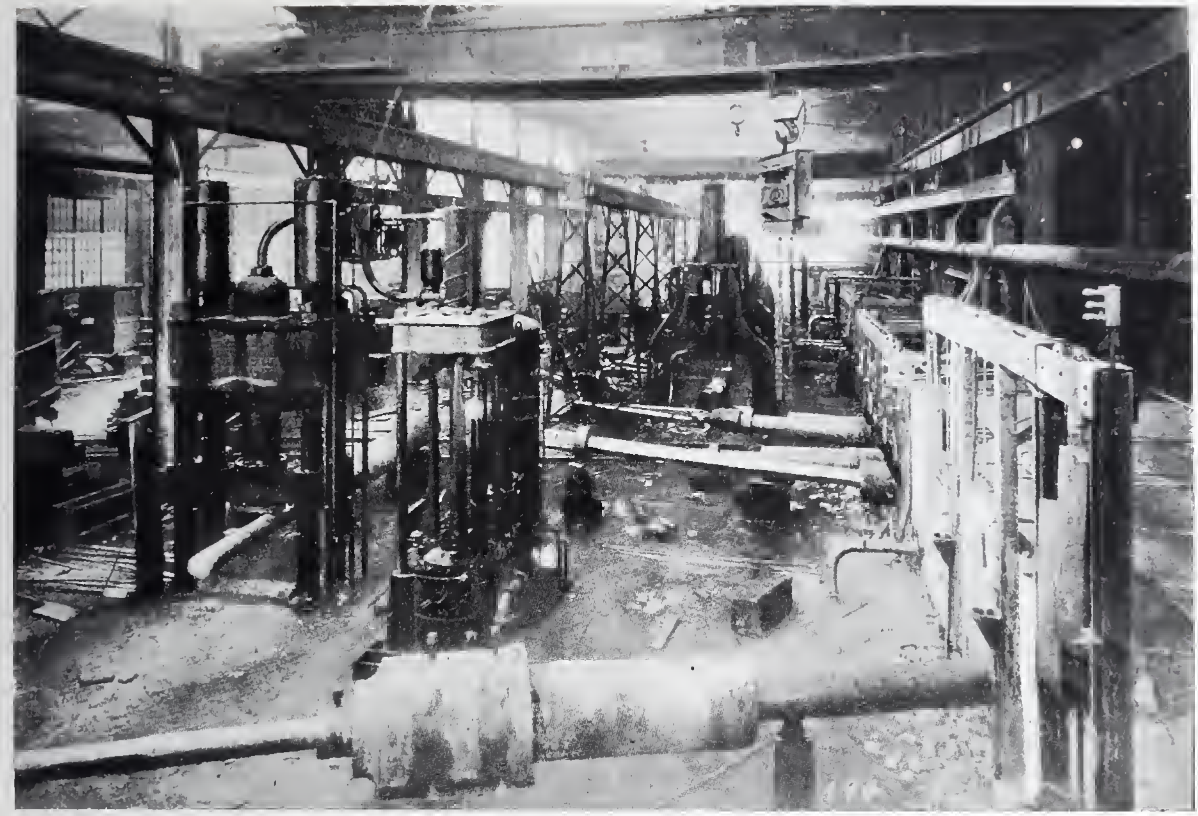


Fig. 188.—Heavy Forge Furnaces at the Sizer Forge Co.'s Works.

The Fuller Engineering Co.]

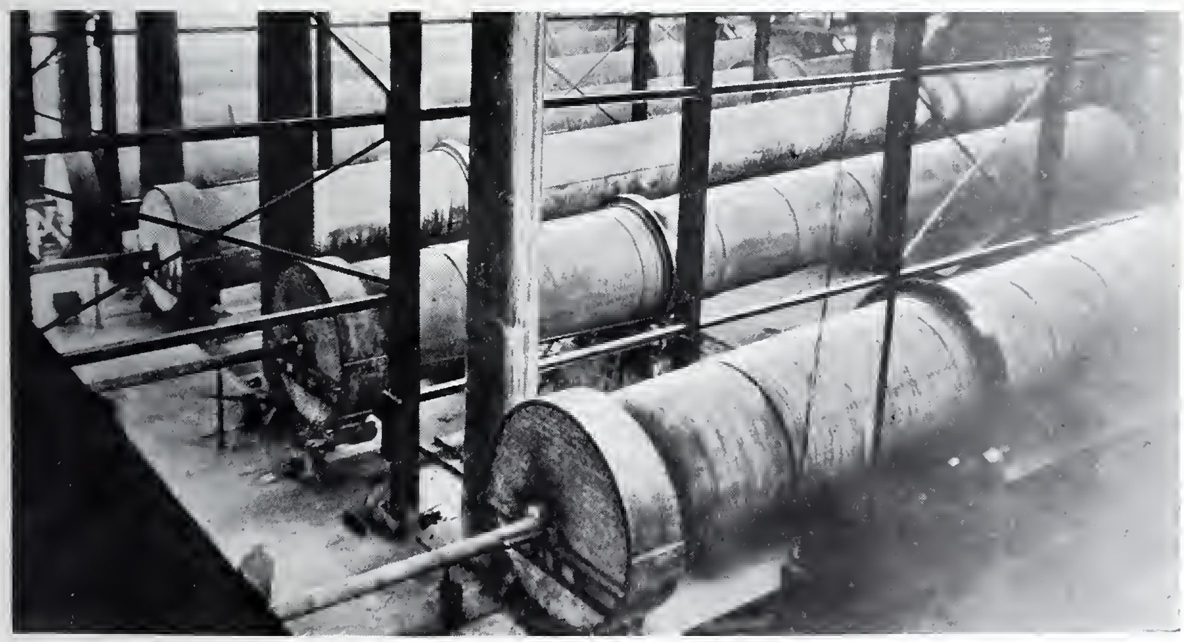


Fig. 189.—Rotary Lime-burning Kilns at Muscle Shoals.

The Fuller Engineering Co.] [*The Fuller Lehigh Co.*

[*To face p.* 330.

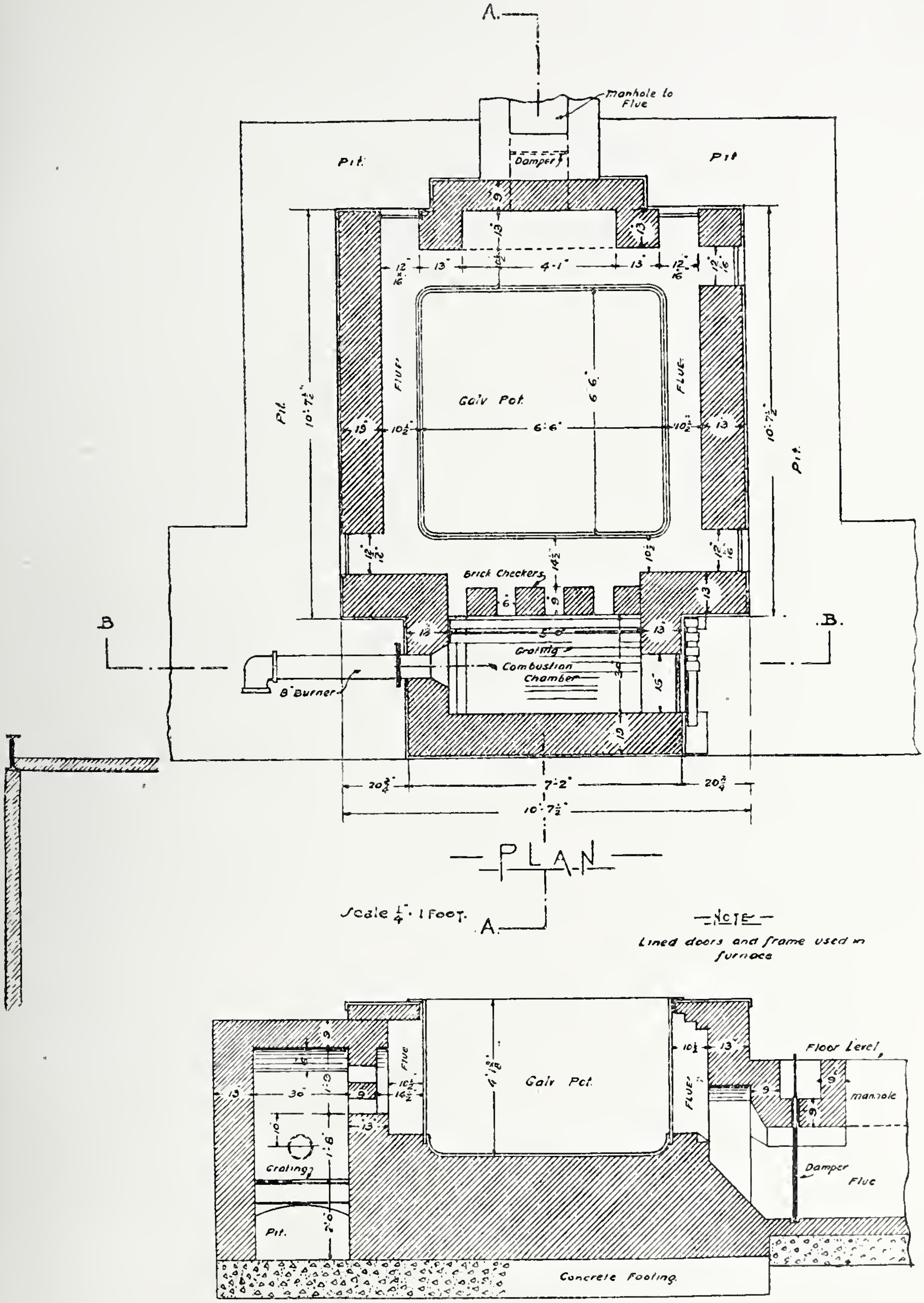


FIG. 190.—Arrangement of Pulverised Coal Fired Galvanising Kettle, showing Side Combustion Chamber and Quigley Burners. (*Quigley Furnaces Specialities Co.*)

of coal were used for smelting 30 tons of ore. On the same furnaces, when pulverised coal fired, only 30 tons of coal were used, showing a saving of approximately $33\frac{1}{3}$ %.

The use of pulverised fuel, as a means of firing rotary furnaces for ore roasting and nodulising, and for calcining of refractory materials, has been very extensively applied, and although the burning of lime for the building trade and for agricultural requirements is not within the sphere of metallurgical applications, a few notes will be given relating to the largest lime-burning plant in existence.

As a rule, lime is burned in vertical retorts or kilns by which means the burned lime is retained in lump form. This type of kiln is generally fired by coal, coke, oil or gas.

Fig. 189 shows an installation of rotary kilns, at Muscle Shoals, U.S.A.

The use of rotary kilns naturally produces a high percentage of fines, a quality often looked upon with disfavour in the builders' world, for a high percentage of "fines" is usually taken as an indication of inferior quality, or that the lime has become partially slaked.

The burning of lime in rotary kilns is considerably less expensive than the cost of operating vertical kilns. The product of the former, although of smaller size, is none the less of as good quality as the lump formation given by the older method of production.

The first cost of a rotary kiln plant is perhaps 50 % greater than that for the set kiln equipment, but the cost of output from a pulverised coal-fired rotary kiln has been shown to be some 20 % to 30 % lower than the cost of burning lime in a producer gas-fired vertical kiln of equal duty.

Where space is no object, the horizontal kiln offers greater facilities for charging, as expensive cable-way or hoisting gear that must be provided for vertical kilns, often as high as 50 ft., is not required.

For hand or producer gas-fired furnaces, 1 ton of bituminous coal of 14,000 B.Th.U. value per lb. will be used for burning $3\frac{1}{2}$ to $4\frac{1}{2}$ tons of lime; in pulverised form, 1 ton of coal will burn about 5 tons of lime, although the operating engineer at Muscle Shoals, G. E. Cox, states that: "The ratio of coal to lime burned was about 2·8 lb. of lime to 1 lb. of coal. The quality of the coal, however, was inferior. With a good grade of coal it is easily possible to burn 3 lb. of lime to 1 lb. of coal."

The average output for a week's run on one of the 8 ft. by 125 ft. rotary kilns, making one revolution in $1\frac{1}{2}$ to 2 minutes, driven by a 30 h.p. motor, was at the rate of 105 tons per 24 hours.

Direct Processses for obtaining Steel from Iron Ore.

The pulverisation of coal, and its application as a fuel in this form, which renders possible the generation of maximum temperatures in contact with metalliferous ores, has suggested, from time to time, the reduction of iron ore to liquid metal without recourse to blast furnace practice.

In November 1920, reference was made in the technical journals to a process of this kind, evolved by the French engineer, Mons. Lucien Basset. It was stated

that the process had been acquired in France by the " Société des Acicrics Basset." An outline of the process is as follows :—

An inclined rotating furnace is heated by means of pulverised coal. High flame temperatures are reached with the aid of air for combustion preheated to 1000° C., but the gases leaving the furnace at the further end of the kiln have a temperature of about 300° C. only. In the waste gases there is present some 44 % of CO, so that these gases can be further used for heating purposes, the high percentage of carbon monoxide being maintained so that a perfectly reducing atmosphere is maintained in the kiln.

It is said that 2500 tons of liquid iron have already been obtained in France at

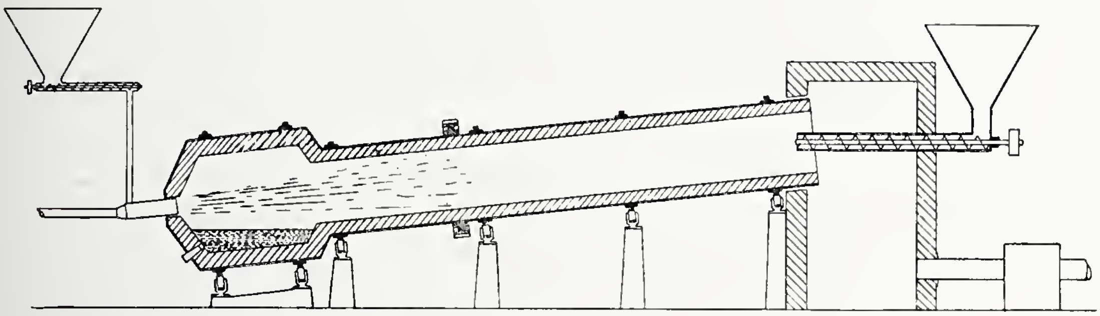


FIG. 191.—" Basset " Direct Process Steel Furnace.

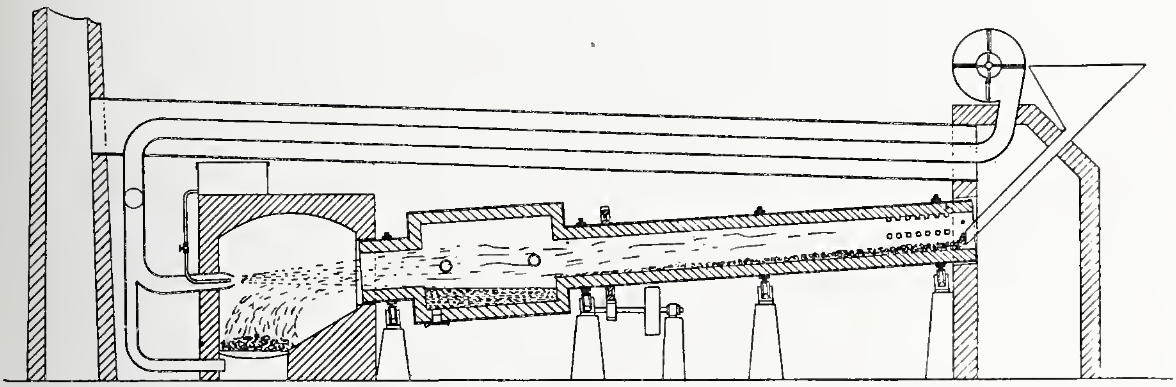


FIG. 192.—Duryee Direct Process Steel Furnace.

the Longwy and Caen works by this process, but little further information has come to hand.

In the Basset kiln the ore is charged at the upper end, and works its way towards the lower end as the furnace slowly revolves. The air which supports the combustion is previously heated in a regenerator similar to that connected with an open-hearth furnace. The furnace shaft revolves at a speed of one-third of a revolution per minute, and the slag is tapped off from the surface of the metal bath.

It is claimed that three qualities of metal have been produced, including pig iron of a grade between grey and white, hard steel, and malleable iron. These results are obtained by varying the ore charge, and the temperature of the process.

The following extracts concerning this process and previous attempts, with illustrations, have been taken from the *Iron Age*, April 13, 1922.

The furnace used in the tests has a length of 40 to 50 m. (131 ft. 2·7 in. to 164 ft. 0·5 in.) and a diameter of 2·5 m. (8 ft. 2·4 in.). At the lower end, where the fuel is burned, it is widened in diameter to be suitable for taking up the molten metal and slag (Fig. 191). At the throat of the furnace finely ground ore is charged, together with the necessary limestone and the coal needed for reduction. Re-oxidation of the metal is prevented, according to the inventor. He professes to be able to burn the powdered coal to carbon monoxide, not to carbon dioxide, whereby re-oxidation of the reduced iron is completely avoided.

In German Patent No. 15356, taken out in 1882, an American, G. Duryee, protected a rotary kiln for the production of iron and steel. As may be seen in Fig. 192, the Duryee furnace is a rotary kiln with a collecting chamber for the fluid metal and slag near the fuel end. The air for combustion is heated by the outgoing gases, the heating is carried out by producer gas and oil, so that the flame should be as neutral as possible. The characteristics of the Basset process, rotary kiln, preheating of the air and neutral flame would therefore appear to be already present in the Duryee process.

Dr. Emil Fleischer, in Patent No. 157582, Oct. 13, 1903, protected a process in which two rotary kilns are to be used, situated one over the other, for the reduction and melting of the iron. The Eisenwerk Jagstfeld, in German Patent No. 282574, Class 18a, Group 3, protected a process by which iron ore is reduced in a rotary kiln, and the reduced iron melted in an annexed shaft furnace. In addition to these three mentioned methods, there are many German and other patents which for many years have proposed the use of rotary furnaces.

Furthermore, from another source, information is forthcoming to the effect that there are records at the Vermaes Patent Office, of The Hague, Holland, giving a description of the Vermaes process of steel making invented by Professor S. J. Vermaes, M.E., teacher at the Technical High School, at Delft, Holland. It is claimed that by this process it is possible to make iron or steel by the use of poor ores and low-grade coal, a rotating oven being also used, the design of same having also been patented in various countries.

In the Vermaes process the temperature of the ore is raised to a high degree in a most economical manner in an oxidising atmosphere, and the ore is then shifted into a close rotating oven of short length, which is heated by gas passing through channels in the walls. Pulverised coal is added to the very hot ore, causing a very quick reduction, the ore being transformed into sintered spongy iron and a gas being formed, which consists mainly of oxide of carbon, without nitrogen. This very rich gas is used to heat the ore, to maintain the temperature in the reducing zone, and for melting the iron in the open hearth.

Careful tests with the Vermaes process, in which uncertain factors were also taken into account, gave the consumption of coal per 1000 kilos of steel at 563 kilos, the coals used in this instance being Ombillin coals, which are generally considered to be of inferior quality.

Returning again to the Basset process, the *Iron Age* says that with powdered coal firing, the blast serves not only for combustion of the coal, but also for dispersion of the coal powder, so that a certain minimum amount of air must be used.

The requirements for the formation of carbon monoxide are therefore much more unfavourable than with the gas producer; and from this standpoint, therefore, it is altogether unexpected that the combustion will be carried out in such a way that practically only carbon monoxide is produced.

If, however, it is assumed that this is possible, and calculations are made of the theoretical temperature of combustion, the following results are obtained :

With pure carbon : Combustion temperature without preheated air to CO—1325° C., to CO_2—2265° C. Low volatile coal of the following composition : Carbon, 86·22; hydrogen, 3·62; oxygen, 2·48; nitrogen, 1·07; ash, 4·71, and moisture, 1·10 %. Combustion temperature without preheated air and without combustion of hydrogen, to CO—1210° C.; to CO_2—2100° C. If the air is heated to 1000°, the following results are obtained : Pure carbon to CO—2025° C.; to CO_2—2990° C. Above-mentioned coal to CO without combustion of hydrogen—1895° C.; to CO with combustion of hydrogen—2195° C.; to CO_2 without combustion of hydrogen—860° C.; to CO_2 with combustion of hydrogen—2930° C.

From the foregoing figures we can assume that Basset, with a good low volatile coal, and combustion to carbon monoxide, and hydrogen to water (notwithstanding his assumption), can reach a theoretical combustion temperature of 2195° C. This in no way predicts the actual temperature.

To throw light on this question, determinations were made on an open-hearth furnace where the gas combustion was known. The gas temperature was 1215° C. and the air 1227° C. This gas gave a theoretical combustion temperature of 2560° C., and the optical pyrometer showed it to be 1710° C. This can be taken as the required theoretical combustion temperature, namely 2560° C.; and a limit of 2500° C. may be assumed as absolutely necessary to melt the iron. To raise this temperature enough carbon must be burned to CO_2 to obtain a gas that contains at least 30 % CO_2, because with the carbon burned to CO, and even all the hydrogen burned, a temperature of only 2195° C. can be produced. These calculations suggest that the Basset supposition regarding his combustion process is not correct, as otherwise the reduced metal in the rotary kiln would not be melted nor a continuous operation be possible.

This gas mixture of three parts CO_2 and seven parts CO will be of great influence on the process in the rotary kiln, and renders improbable the prevention of re-oxidation of the reduced metal. The equilibrium diagram between carbon monoxide, carbon dioxide, and ferrous oxide shows that at 1000° C. the CO_2 amounts to only 23 %. At 1600° C. this drops to 6 %. In our gas mixture the CO_2 is 30 %, and it is clear re-oxidation would take place and lead to loss.

If the sponge contains carbon, a part of this oxidised material will be again reduced on melting, but the amount will be noticeable only if very pure ore is used. If the ore contains much gangue, the silica slags with the ferrous oxide, and the loss will be very great. The carbon of the metal produced will depend on the amount of re-oxidation of the iron, and the composition of the slag and the temperature in the collecting chamber. Only with very high temperature and the use of pure low silica ore will it be possible to produce soft steel. If ores high in silica

are used, a steel-like product will be the result, between steel and pig iron, that must be refined in a second process. This will be the case under all conditions, if ores high in phosphorus are used because considerable phosphorus will be taken up by the metal.

There is no question of the possibility of making iron and steel direct from the ore in a rotating furnace. The problem is to reduce the process to a profitable commercial basis.

It remains to be seen whether this fresh attempt to produce liquid iron and steel direct from the iron ore can be successfully established.

CHAPTER XV

THE FIRING OF LOCOMOTIVE BOILERS WITH PULVERISED FUEL

Recent Appliances—The Chief Features of Pulverised Coal as a Locomotive Fuel—Rapidity of Loco Steaming and Loco Fuel Losses—Robinson Equipment on the Great Central Railway—Spontaneous Combustion and "Packing" in Tender—Firebox Arches and "Honeycombing"—Conversion of Existing Types of Locomotives—Huwyler Smoke-Prevention Device—Various Grades of Fuel used on American Locomotives—The Fuller Locomotive Equipment—The Lopulco Locomotive Equipment—Tests on Lehigh Valley Railway—Pulverised Peat as a Locomotive Fuel in Sweden—Outstanding Advantages of Pulverised Peat—Swedish State Factory (The Ekelund and Porat Processes).

The high hopes of a wide use of pulverised fuel as an efficient means of firing locomotive boilers have not yet been fulfilled. The causes of delay in this development are such that additional experience is necessary before steady running results can be relied upon. Two difficulties have not yet been entirely overcome, viz. ash accumulation or "honeycombing" at the flue tube sheet in the firebox; and excessive wear or burning out of refractory arches in the combustion chamber.

Sufficient experience has, however, been gained to ensure success with certain grades of coal and when locomotive fireboxes are of such size and design that proper arrangement of refractory linings can be fitted therein.

The work that must be carried out in order to convert hand-fired locomotives to powdered-coal firing is not excessive, and the equipment is not at all complicated; for instance, the Fuller apparatus, referred to in greater detail later, has been designed with reliability and simplicity as its two outstanding features. For this system, as a rule, standard brick arches are used. The burners are made as large as possible, so that the velocity of the entering coal-dust mixture is low, and a cutting flame, with consequent damage to the refractory brickwork, is avoided. The two screw feeders are geared to a slow-speed, two-cylinder reciprocating engine. Either burner can be used for maximum feed, should this be necessary. The feeder engine can be run off the round house steam supply until 15 lb. loco boiler pressure is developed. The engine will then continue to run under all pressures from 15 lb. to 200 lb. per sq. in. Three hundred % feed regulation can be effected from the cab control and 600 % by shifting over the gear-eontrol lever. A steam turbine fan is used to supply air at 2-in. (w.g.) pressure. The general assembly of equipment is shown in Fig. 193.

It can be taken that at least 20 % net saving in fuel used for hand-fired locomotives can be made when the coal is burned in pulverised form.

The diagram, Fig. 194, shows a comparison of the fuel losses in locomotive boilers, when hand fired and when using powdered fuel. That an economy such as this would be of extreme importance to any railway company is apparent, but whether pulverised

fuel firing for this purpose will advance as rapidly as the supply of electric power and conversion of railway stock to electric drive, remains to be seen. The author hopes that, in countries such as Great Britain, complete electrification of railways will be a *fait accompli* at an early date, and that the use of pulverised fuel will assist in the economic generation of the power required.

The International Railway Fuel Association of America appointed, in 1914, a Committee to investigate the question of utilising pulverised coal, and this Com-

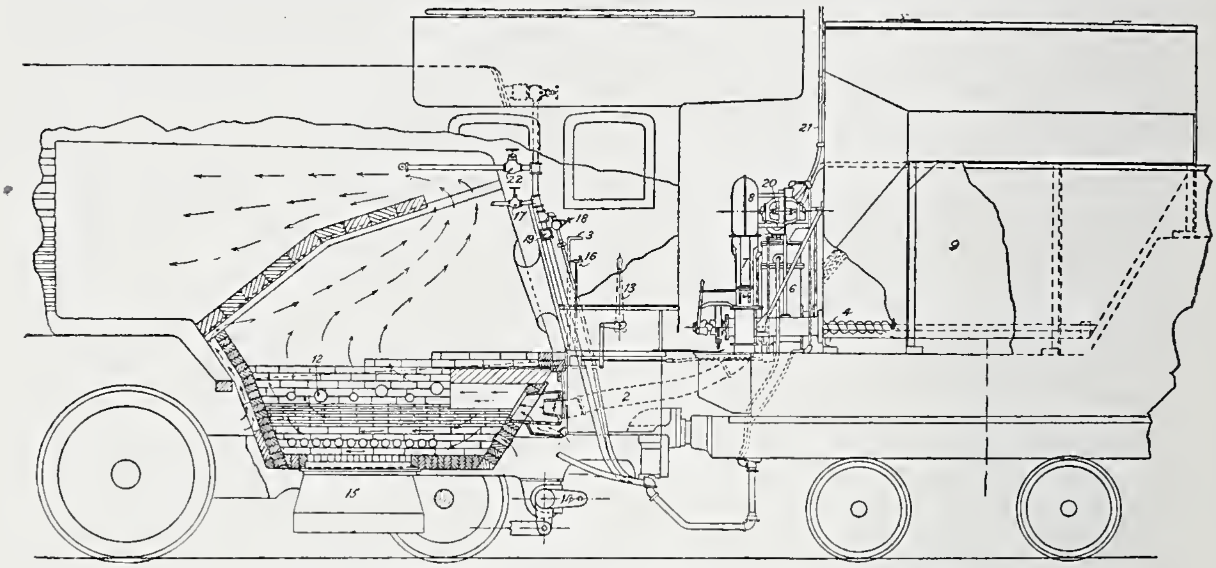


Fig. 193.—" Fuller " Locomotive Pulverised Coal Equipment.

1. Burner.
2. Coal and Air Conveying Pipe.
3. Control Lever for Natural Draught Butterfly Valve.
4. 4″ Feeder Screw.
5. 4″ Quadruple Coal Dust Feeder.
6. $3\frac{1}{2} \times 2\frac{1}{2}''$ Two Cylinder Feeder Engine.
7. Blower Connecting Pipe.
8. Fan Casing.
9. Tank for Pulverised Coal. Capacity 3 tons.
10. Filling Hole.
11. Gear and Clutch (700% Overall Variation).
12. Side Air Ports.
13. Side Air Port Control Lever.
14. Slag Pan Dumping Lever.
15. Slag Pan.
16. Coal Feed Control Wheel.
17. Stack Draught Blower Control Valve.
18. Control Valve for Turbo Fan.
19. Control Valve for Coal Feeder Engine.
20. Steam Turbine Blower.
21. Blower Turbine Exhaust.
22. Round House Steam Connection for starting up from cold.

mittee subsequently recorded its views as to the advantages of this method of firing. These conclusions are given in full on pp. 341 to 343.

Pulverised coal can be delivered to the locomotive tender very rapidly, normally at the rate of 1 ton per minute. Engines can operate, moreover, for longer runs than hand-fired locomotives, with which distance run is a function of the time, depending upon the clinker formation on the grate bars. The " blinding " effect produced when the fire door is opened for hand firing is a source of danger which is also removed when pulverised fuel is used.

Recent Applications.

Some notes upon tests carried out by J. G. Robinson on the Great Central Railway in England have appeared in *The Engineer*. These tests, although encouraging,

were unfortunately discontinued in favour of the investigation of colloidal oil as a fuel for firing locomotives, with which fuel much progress was made by Robinson. Notes on these particular tests are given at pp. 345–346.

In many countries it would be of great value to render serviceable for railway or general industrial uses the great variety of fuels which up to now have not received serious attention.

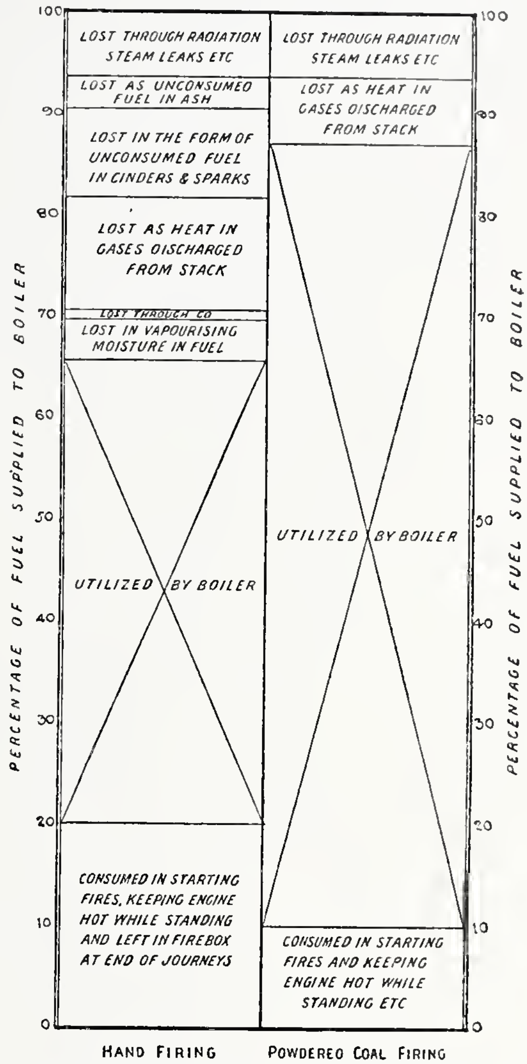


FIG. 194.—Approximate Comparison of Heat Losses on Hand Fired and Pulverised Coal Fired Locomotive.

If the low-grade fuel and lignite in India, for instance, of the Khost, Dandote, Assam, Garo Hill and other districts can be used with as great success as has been achieved on the Lehigh Valley Railway locomotive when burning Western American lignite, then a new situation will be presented. The utilisation of these great deposits of fuel, of too inferior a grade to render mining operations with a view to their use on ordinary grates satisfactory, will become practicable. Certain experiments have been made on the Swiss Federal Railways, but there has been no evidence as yet of any extensive use in Switzerland.

In Sweden there are no coal deposits, but there exist large supplies of peat. In 1916, the Swedish State Railways Department experimented with powdered peat as a fuel for its locomotives. Several locomotives are now operating in that country on pulverised peat with which is mixed a small proportion of pulverised bituminous coal, and records of the results are given at p. 358.

Quite an extensive use of this system of firing has taken place in Brazil. The Central Railway of Brazil, after testing twelve engines under daily running conditions, extended the application of the system to twenty additional locomotives. The equipments used are of the Lopulco type. The following notes have been taken from an article in the *Railway Mechanical Engineer*, Vol. 91, No. 11, in which there appears a full description of the pulverised coal plant and the engines employed on this line in Brazil.

With about 500,000 square miles of territory containing deposits of coal which can be easily mined and transported to the industrial centres, Brazil has been forced to import coal from Europe and America because, up to the present time, it has been found impossible to burn the domestic coal successfully. In 1915 there were imported 1,346,147 metric tons, 561,150 of which came from America.

The difficulties encountered in the use of Brazilian coal are due to its large content of sulphur and iron pyrites, which, combined with the ash, form so much clinker that efficient combustion on ordinary grates is impossible. The analysis of the coal is as follows :—

Moisture from 2 to 8 %; sulphur from 3 to 9 %; volatile from 14 to 28 %; fixed carbon from 34 to 58 %; ash from 26 to 30 %; the relatively high volatile and carbon content makes it a very desirable fuel if only it can be burned successfully.

As a result of investigations, the Central Railway of Brazil decided to instal a pulverised fuel-preparing plant, having a capacity of 15 tons per hour, to be used for steam locomotives and stationary boiler equipment at shops located at Barro do Pirahy, some 65 miles north of Rio de Janeiro.

The first twelve locomotives equipped to burn powdered fuel were built and fitted with the necessary equipment in America. Each engine weighs 172,000 lb. and has a maximum tractive effort of 28,300 lb. The gauge is 5 ft. 3 in., cylinders $21\frac{1}{2}$ in. by 28 in., driving wheels 68 in. The total heating surface is 2149 sq. ft. and superheater surface 428·2 sq. ft.

Prior to 1915, there were in operation many experimental pulverised coal-fired locomotives on the railway systems in America. When America entered the war it became necessary to discontinue the tests on three experimental engines, and make every locomotive available for hauling freight trains throughout the country.

Since the year 1919, a fresh start has been made by the Fuller Engineering Co., notably on the Lehigh Valley Railway locomotive, concerning which the following notes have been taken from a paper published in *The Railway Engineer*, July, 1920.

Fig. 197 shows a pulverised coal-fired locomotive on the Lehigh Valley Railway line hauling a 38-car freight train, 982 tons, or 82 tons above rating, up a 0·58 % grade speed 20 m.p.h. Fig 196 shows the tender equipment used. The locomotive is run on a mixture of 55 % raw anthracite silt, and 45 % bituminous coal. Full steam pressure is maintained easily at all times, and the anthracite silt contains 38·42 % of ash, and has a B.Th.U. value of 9675, while the soft coal which is mixed with this has an ash content of 11·6 % and a B.Th.U. value of 12,650. Analyses of coal used and particulars relating to tests made on a number of American railways prior to 1916 are given at pp. 349–350.

In Italy, owing to the scarcity of fuel, it was decided to equip two new heavy consolidation type locomotives for burning pulverised fuel, the object being to determine whether the vast fields of Italian lignite could be used for this purpose. Little alteration was found necessary in the locomotive proper, the only change of importance being in connection with the tender design, a U-shaped tank being substituted for the former type constructed for lump coal, the tank being moved bodily on the tender 7 in. toward the rear, in order the better to distribute the weight on the front and rear axles. In view of the fact that only one coal-pulverising plant is to be erected in the first instance, it was considered advisable to provide for a much larger fuel capacity on the tender than would otherwise be required, and a coal tank holding 10 metric tons instead of 6 metric tons has, therefore, been provided.

FIG. 195.—ENGINE TAKING IN FUEL AT PULVERISED COAL DEPOT.

The Fuller Engineering Co.] *[The Fuller Lehigh Co.*

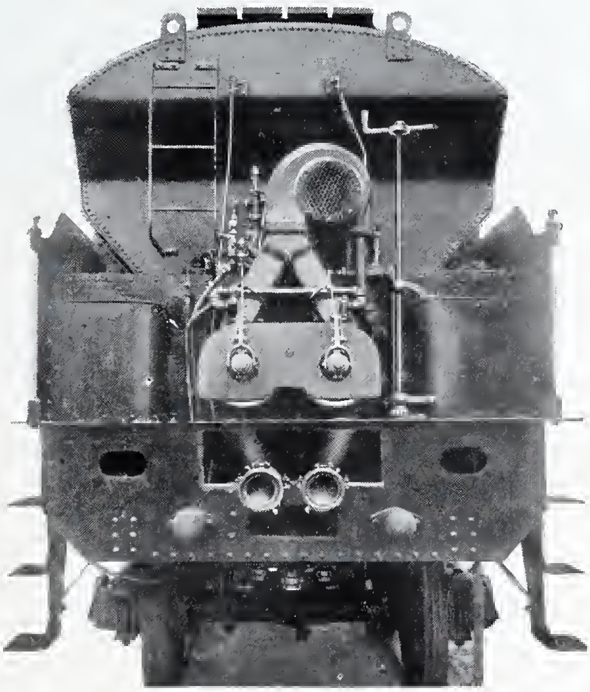


FIG. 196.—FULLER LOCOMOTIVE EQUIPMENT ON ENGINE TENDER.

The Fuller Engineering Co.]
[The Fuller Lehigh Co.

[To face p. 340.

Fig. 197.—Lehigh Valley Railway Freight Locomotive and Train.

The Fuller Engineering Co.] [*The Fuller Lehigh Co.*

The average analysis of Italian lignite to be tested on the locomotives shows that it contains approximately :—

Ash 10 %; volatile 40 %; fixed carbon 30 %; moisture 20 %.

There are so many lignite mines in Italy, in different localities, that it is very important to utilise this fuel as far as possible in place of costly imported coal.

The experiments appear to have been conducted on makeshift lines, which is much to be regretted. A trial pulverising plant and loco equipments have been in use and tests carried out on lignite. The pulverised fuel used was obtained from a cement works at some distance from the locomotive sheds. Lack of experience and the crude nature of the tests seem to have resulted in comparative failure. The burning of fuel in a locomotive firebox is, perhaps, the most exacting application of any, and should be undertaken only when expert advice and assistance are available. If, in addition, fuel such as lignite is to be used, the advisability of enlisting expert co-operation becomes even greater.

A similar plant and locomotive equipments for identical types of railway engines are also on the point of being tested on the Netherland State Railways.

The Chief Features of Pulverised Coal as a Locomotive Fuel.

The benefits to be derived from the use of powdered coal for firing locomotive boilers as enumerated by the Committee appointed by the Railway Fuel Association of America are :—

" (1) *Sustained Boiler Horse Power.*—With powdered coal the tendency toward the more uniform, intense and sustained firebox temperature, as well as the automatic, continuous stoking of the fuel and the burning of the same in suspension; feeding of practically dry fuel to the furnace; reduction in the clogging and leakage of flues and the reduction in the various heat losses, should all tend to maintain the boiler capacity at its maximum effectiveness under varying conditions.

" (2) *Ability to run Locomotive for relatively long, continuous Mileages or Periods.*—The length of continuous runs for road or yard steam locomotives is limited to from 100 to 200 miles . . . by the accumulation of clinker on the rocking and dead grates, which necessitates ashpit facilities and labour for removing.

" As locomotives burning oil are being regularly and successfully operated on runs from 300 to 450 miles each way, the same should be entirely feasible when burning powdered coal.

" (3) *The Firing of the Boiler entirely Automatic.*—No fuel whatsoever supplied to the furnace by hand shovelling. The burning of coal on grates requires the skilful distribution of the fuel to the exact points where needed over the grate area, in order to avoid the liability of holes in the fire, or to prevent waste of fuel through banking and clinkering, with consequent steam failure. With powdered coal there is no hand firing whatever, all fuel being supplied automatically by mechanical means."

(4) *No Cinders, Sparks or Smoke.*—After reviewing previous devices for the reduction of engine smoke, this report goes on to say that : " This method, therefore, seems to be the logical solution of the question at engine-houses, terminals and on the road, and the one that should greatly reduce the loss of heat and fuel cost resulting

from imperfect combustion in existing and future locomotives. Moreover this method of combustion should avoid the necessity for the removal of engine-houses, yards and terminals outside the smoke and cinder restrictive areas of large cities, at enormous expense and inconvenience, as has been considered, for example, by the city of Chicago.

" (5) *Material Reduction in Cylinder Back Pressure* through greatly enlarged exhaust passages. The elimination of ash-pans, grates, smoke-box diaphragm, baffles and nettings substantially reduces the retardation of the products of combustion through the boiler. This, in combination with the means employed for producing combustion with powdered coal, enabled the use of exhaust passages enlarged from 100 to 200 % in area, as compared with those required for burning coal on grates. The enlargement of the exhaust passages will greatly reduce the cylinder back pressure losses, which under certain speed conditions frequently equal as much as 25 % of the engine power developed.

" (6) *Saving in Inspection, Maintenance and Operation through the Complete Elimination of Grates, Ash-pans, Dampers and Operating Gear, Smoke-box Diaphragms, Baffles, Nettings, Spark Hoppers and Hand Hole Plate, Coal Pushers, Firing Tools, Squirt Hose and like equipment.*

" (7) *Enclosed Fuel Container prevents the Spilling and Loss of Coal, and its being subjected to Snow, Rain or other Unfavourable Conditions.*

" The general practice with all solid fuel is to use it in the locomotive in its raw state as furnished from the mines. For example, run-of-mine bituminous coal from a wet mine is usually loaded into an open car, where it may take on additional moisture from the rain and snow, then dumped into a wet pit, conveyed into an open storage bin, and finally dumped into an open tender. The result is that the coal when fed into the furnace is frequently in the nature of a slushy mixture of coarse and fine coal, which must be dried out by absorption of heat . . . before it can become usable in generation of steam.

" With powdered coal the fuel is supplied to an enclosed air-tight container on the tender (suitable for either powdered or liquid fuel), prepared to uniform fineness and thoroughly dried, so that when fed to the furnace it immediately produces effective heat.

" Furthermore, the coal is not touched by hand or shovel from mine car to furnace, and there is no loss by pilfering, dropping from tender container, gangways, through holes in deck, or by firemen shovelling undesirable fuel off the tender on right-of-way.

"(8) *More uniform Furnace Temperature, reducing the liability of Fire-box and Flue Leakage.*

" (9) *No Special Fuel required for Firing Up.*

" (10) *Ability to make use of Inferior Qualities and Grades of Solid Fuel.*

" (11) *Reduction of Heat Losses from Combustion.*—Locomotive boiler losses (the percentage of loss increasing with the rate of firing, the character of induced draught and the reduction in the relative grate area) are largely contributed to by the heat produced by combustion that is carried out by the smoke stack; by excess of air entering through the grates and fire doors; loss by unconsumed coal that is

carried out of the smoke stack in the shape of cinders and sparks; stand-by losses such as firing up, drifting, stoppage at the termination of the trip or day's work; radiation; vaporising moisture in coal; unconsumed carbon and ash and smoke. Taking into consideration the effect of burning powdered coal in suspension on the various heat losses enumerated, *it is conservative to place the saving to be effected at 25 % of the coal fired, actual performance to date having shown as high as 30 to 40 % saving.*

"(12) *No liability to Set Out Fires.*

"(13) *Reduction of delay for Building, Cleaning or Dumping. Fires at Terminals and Cleaning Flues and Smoke-boxes.*—The time required to perform this work on steam locomotives represents a large percentage of the maximum non-productive delay to power, and is directly responsible for much road and yard crew and shop expense.

"With powdered coal there are no grate fires to clean; the extremely fine nature of the ash and absence of cinders result in practically no accumulation in the flues or smoke-box.

"(14) *Elimination of Ash-pit Tracks and Ash-handling Facilities at Terminal and Intermediate Stations.*—The only non-combustible residual matter to be disposed of from the powdered coal furnace is a slag which is of a glassy nature and composed principally of silica, iron and aluminium. This, being of a brittle and easily removable nature when solidified, can be readily removed without the usual labour, ash-pit track, grate and ash-pan cleaning and clinkering and ash-handling facilities and equipment. When fuel is low in ash, and particularly in iron, sulphur and aluminium, the amount of slag produced is almost negligible.

"(15) *No Clogging or Cutting Out of Superheated Units and Boiler Flues.*—As the proper burning of powdered coal produces no cinders, and as the ash is of the nature of an impalpable powder, scouring in tendency, there is no clogging of the superheater or boiler flues, and the accumulation of ash is practically nil.

"(16) *Reduction of Poisonous Gases through the Smoke Stack.*

"(17) *No Cinders or Ashes to Destroy Ballast or Wooden Cross Ties or Trestles.*

"(18) *Less Educational and Physical Requirements of Labour for Firing.*"

Rapidity of Loco Steaming and Loco Fuel Losses.

With regard to the rapidity with which locomotives can be brought up to steaming pressure when fitted with powdered-coal burners, figures representing the average of a large number of actual observations were recorded; these figures show the following results for a fuel composed, approximately, of 60 % anthracite and 40 % bituminous.

Initial Temp. of Water in Boiler.	Time to Raise to 150 lb. steam pressure.
70°	52 minutes.
100°	44 ,,
200°	35 ,,

From the foregoing notes and extracts from the Proceedings of American Institutions it will be seen that considerable attention has been, and is still being, directed

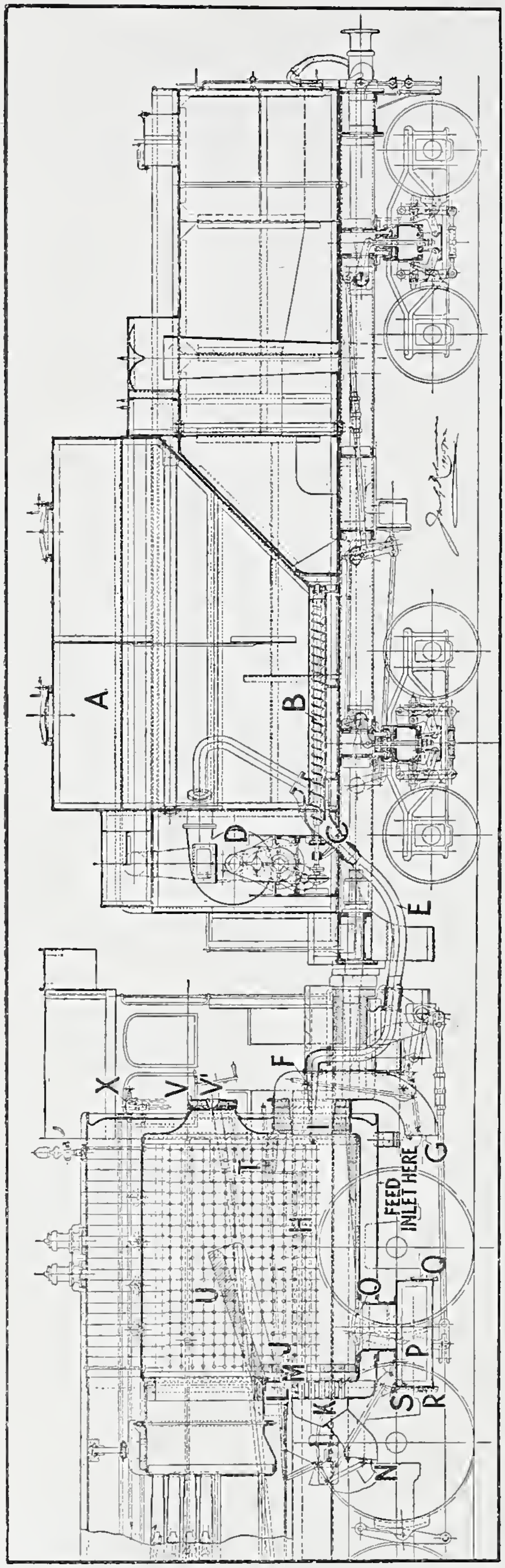


Fig. 198.—Great Central Railway Goods Locomotive as fitted with Robinson Pulverised Fuel Equipment. (*Modern Transport.*)

towards the equipment of heavy freight and passenger locomotives with pulverised fuel burning apparatus.

In the *Railway Age Gazette*, Vol. 62, No. 24, attention is also called to the fact that only two-thirds of the total fuel purchased for locomotive operation is actually utilised while hauling trains, the remaining one-third going into the so-called "standby" loss, including the cleaning, building and maintaining of fires on grates during the period the engine is standing or otherwise not utilising steam for locomotion, either light or with train. Confirmation of this statement is given in Fig. 194.

Robinson Equipment on the Great Central Railway.

The arrangement of Robinson's apparatus for use with pulverised coal and as fitted on a 2–8–0 type Great Central Railway locomotive is shown in Fig. 199*a*. A description of this appeared in *Modern Transport*, June 3rd, 1922. In the arrangement, as shown in the drawings, Figs. 198 and 199, the pulverised fuel is conveyed from the hopper A by the feed screws B to the mixing nozzle C, from which

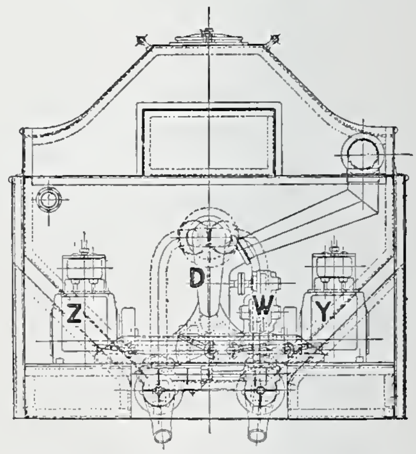


Fig. 199.—Cross-sectional View of Robinson Pulverised Fuel Equipment on Great Central Railway Goods Locomotive. (*Modern Transport.*)

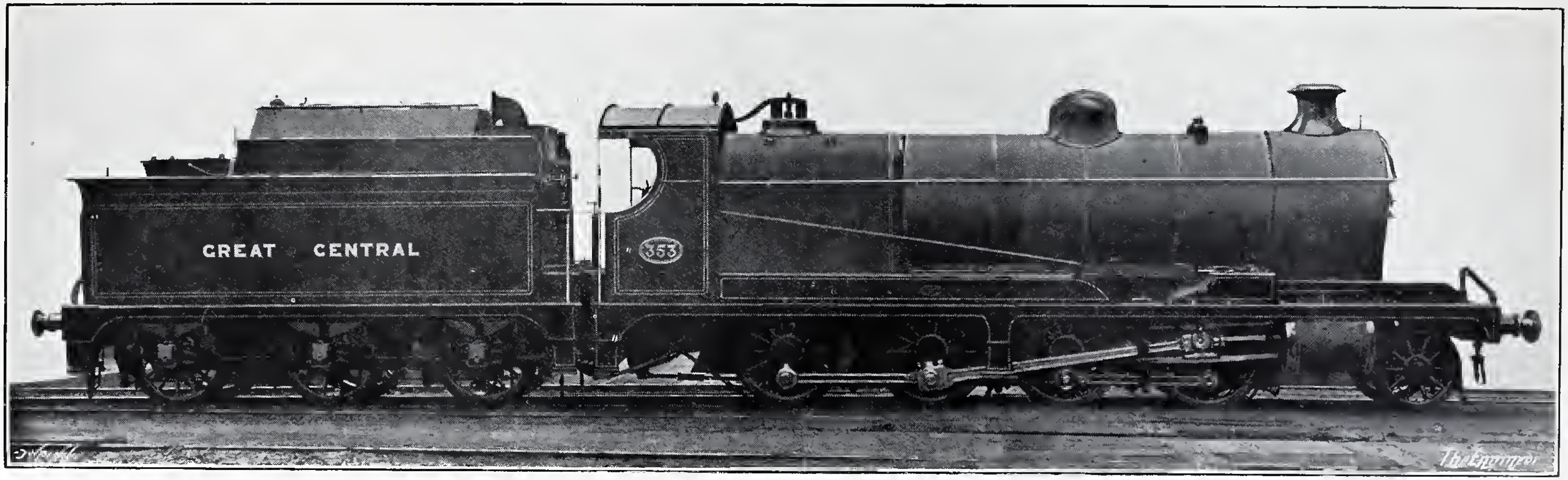


FIG. 199*a*.—GREAT CENTRAL RAILWAY GOODS LOCOMOTIVE AS FITTED WITH ROBINSON PULVERISED FUEL EQUIPMENT.

Modern Transport.]

[*To face p.* 344.

it is carried forward by the air blast supplied by the fan D through the flexible E to the inner nozzle F of the burner I, where it is met by a further supply of air admitted through the supplementary air valve G, and thence into the brick-lined furnace H. The front wall of the furnace is provided with a number of openings J, through which a further supply of air is admitted by means of the damper box K, tubes L and hollow chamber M, the supply being regulated by damper door N. In the bottom of the furnace is a slag opening O leading to the air-cooled slag box P, which is provided with doors Q and R for removal of slag, and also a damper door S to give a further supply of air to the furnace through the opening O. The furnace has two brick arches, a primary arch T covering the rear portion, and a secondary arch U over the main portion of the combustion space. The fire-hole is covered by a brick-lined door V, provided with a sight hole V′. The steam cocks controlling the engines driving the feed screws and fan are located at X. The high-speed engine drives the fan D through the enclosed train of gears, and a similar engine drives the feed screws through a set of two-speed spur gearing. Arrangements are made so that either engine can, if required, drive both fan and feed screws through dog clutches. An arrangement is also provided to supply the engines driving the fan and feed screws with steam from an outside source when there is no steam in the boiler of the engine.

The following is a summary of the various types of fuel used on 2–8–0 type goods locomotive No. 966 :—

Coal.	Fixed Carbon.	Volatile matters.	Moisture and other matters volatile below 212° F.	Ash.	Calorific power. B.Th.U.
	%	%	%	%	
Mitchells main	62·01	22·99	2·60	12·40	13,966
Warsop slack	43·39	27·51	6·30	22·80	11,218
Elsecar	64·33	22·88	1·87	10·92	13,659

A test was made with this locomotive, burning Elsecar coal and hauling a train of eighty empty coal wagons and brake, representing approximately 510 tons behind the tender, from Ashburys East to Crowden, on the Great Central Railway, a distance of 15 miles 51 chains, with an average gradient of 1 in 180 and a maximum of 1 in 100. The following figures give the result of the test :—

Grading of fuel :	
Through 60 mesh	99·5 %
,, 90 ,,	97·5 ,,
,, 120 ,,	94·4 ,,
,, 200 ,,	86·9 ,,
Moisture	1·87 ,,
Ash	10·92 ,,
Combustible matter	87·21 ,,
Calorific value of fuel	13,659 B.Th.U.
Total water used	18,400 lb.
Total fuel consumed	2,660 ,,
Evaporation per lb. fuel	6·92 ,,
Factor of evaporation	1·35 ,,
Equivalent water evaporated from and at 212° F.	9·34 ,,
Overall efficiency	66 %

In view of the severe nature of the stretch of line over which this trial was made, the gradient being in many places anything from 1 in 100 to 1 in 117, the evaporation of 6·92 lb. per lb. of fuel may be considered most satisfactory.

Spontaneous Combustion and "Packing" in Tender.

The risk of any serious fire due to spontaneous combustion on a locomotive tender is small. The fuel tanks should be made entirely closed, so that any fire occurring in the fuel can be smothered by closing the air-tight doors; in fact, burning fuel has been pumped from storage right into a loco container, the doors closed, and the hot fuel used in the firebox of the engine.

There should be no difficulty in keeping pulverised fuel dry, for reabsorption of moisture should not occur to any deleterious extent if the pulverised coal is contained in a closed tank, since under these conditions the fuel cannot readily absorb any moisture from the atmosphere. In an open tank, or one with defective doors, there may be a tendency under change of climatic conditions for moisture to collect inside and become transferred to the fuel.

Pulverised coal will tend to "pack" in a tank if it lies for some time undisturbed. The application of compressed air to the bottom strata will effectively recondition the fuel.

In the latest designs of locomotive fuel tanks, special attention has been given to the prevention of the fuel from "bridging over" in the tank, feed screws of duplex construction being arranged in such manner that "bridging over" cannot take place, and uneven feeding of the fuel to the burners, resulting from the hanging up of fuel in the tender, is no longer a cause of intermittent firing. The duplex feed screws of the standard Fuller equipment are clearly shown in Figs. 200 and 201.

Firebox Arches and "Honeycombing."

The rapid wearing away of the refractory lining of the firebox, and especially that of the return arch, has been to a very great extent overcome by the introduction of secondary air to cool the surfaces in the hottest zone. The manner in which air can be admitted for this purpose is shown in Fig. 203.

The use of Zirconium refractory blocks for this work may eventually become a recognised practice, for Zirconium will withstand a temperature of 2500° F., and the problem of making refractory blocks, pyrometer tubes, crucibles, muffles, etc., from Zirconium appears to have been to a great extent solved. Ordinary high-grade refractories will, however, last for many months in daily use, provided that due attention is given to those parts which receive the hot impinging flame from the burner, and periodical repairs are made.

The life of brickwork in a loco firebox and of the brick arches greatly depends upon the nature of the fuel used and the manner in which this is introduced. In view of the small percentage of ash in anthracite fuel, the life of brickwork is perhaps longer with this than with bituminous coal or lignite, which contain much higher quantities of ash.

When firing anthracite in this manner, brick arches have lasted some eleven or twelve months of fairly continuous use, whereas, under more severe conditions, the

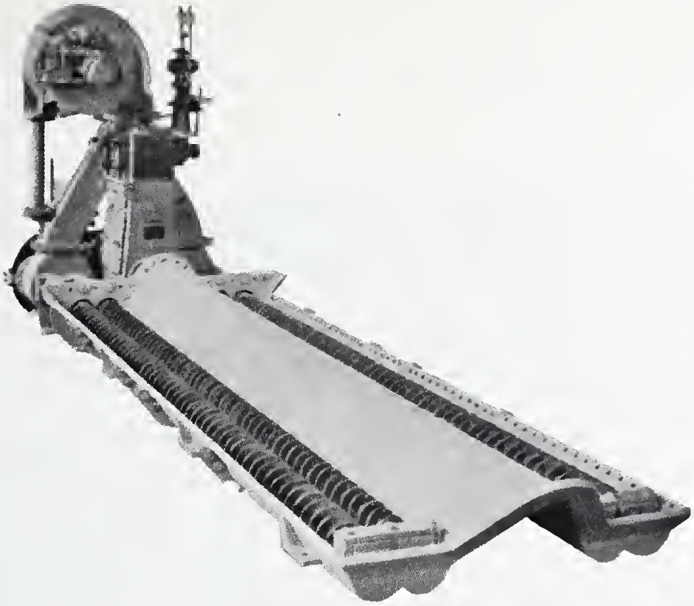


FIG. 200.—FULLER LOCOMOTIVE EQUIPMENT, SHOWING BASE OF COAL CONTAINER AND DUPLEX FEEDERS.

The Fuller Engineering Co.] [*The Fuller Lehigh Co.*

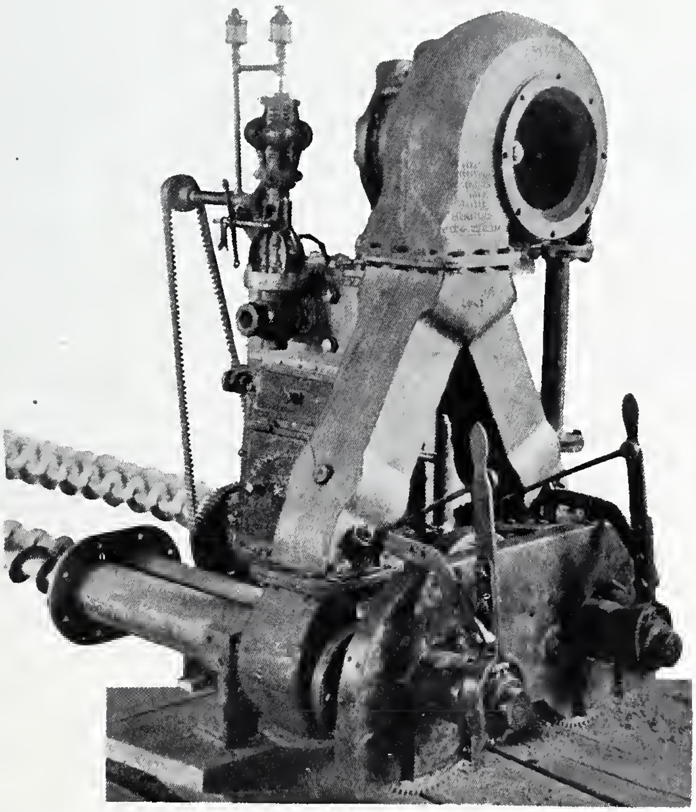


FIG. 201.—FULLER LOCOMOTIVE EQUIPMENT, SHOWING DUPLEX SCREW FEEDERS.

The Fuller Engineering Co.] [*The Fuller Lehigh Co.*

[*To face p.* 346.

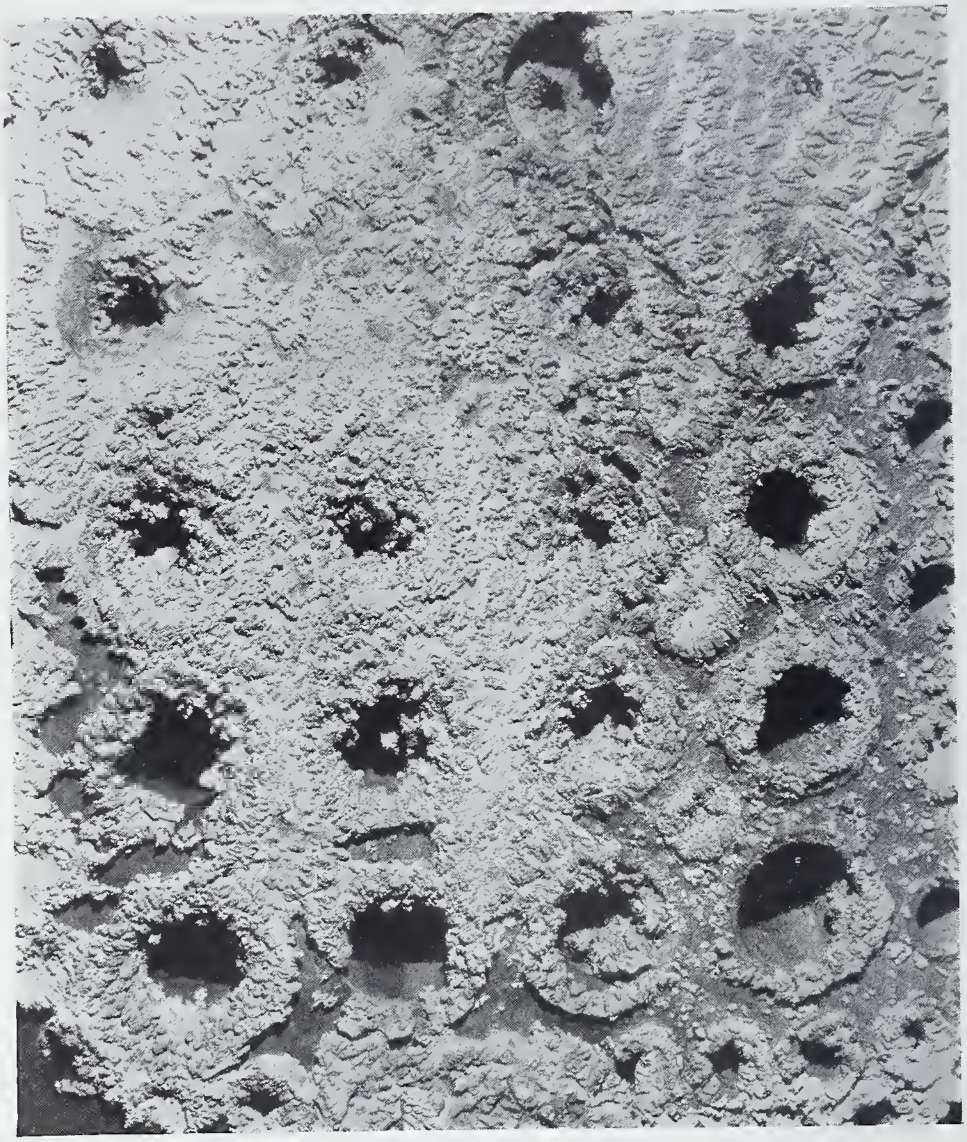


Fig. 202.—" Honeycombing " on Tube Sheet of Locomotive.

life of arches and certain portions of the lining, where the flame impinges, or becomes deflected, may be no longer than three or four months.

The main difficulty up to now has been the accumulation of ash particles on the tube sheet of the boiler. This deposit may grow rapidly under certain conditions, and a bad example is shown in Fig. 202. When accumulation of ash dust occurs to this extent, the fire tubes become blocked, the boiler ceases to function, and a burn out of the tube sheet may be the result.

Much less trouble of this kind is experienced with some fuels than with others; anthracite, for instance, on account of its low ash content, presents no difficulty; but high-volatile high-ash fuels, especially those of the lignite grades, must be burned under conditions which will prevent "honeycombing."

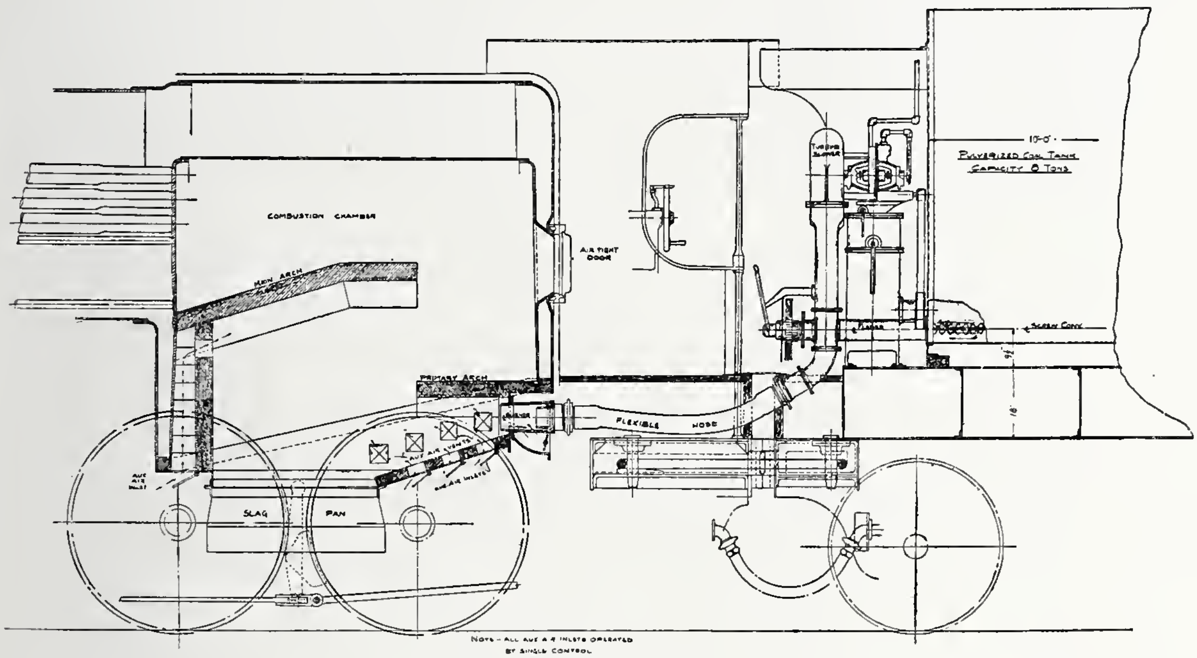


FIG. 203.—Arrangement of Air Ports at Burner and under Return Arch (*Fuller System*).
(*The Fuller Engineering Co.*) (*The Fuller-Lehigh Co.*)

It is for this reason that most careful attention should be given to the type of locomotive equipment used, and to the design and arrangement of refractory brick-work, air-inlet ports, and the return arch in a firebox.

Ash thrown upon the tube sheets can usually be removed by hand, and in practice this should be done after each trip.

The use of smoke-prevention devices, such as the one described later, will help towards overcoming the "honeycombing" difficulty. (See Figs. 204, 204*a*, *b*, and *c*.)

Conversion of Existing Types of Locomotives.

At the present day, locomotives must take in pulverised fuel at a main depot, but it is confidently expected that in the near future self-contained and compact

coal pulverising units will be available for direct installation upon the tenders of locomotives. It will then be possible to bunker small or crushed coal, and to pulverise this as required for firing the boiler. The costly outlay upon heavy production machinery will then be unnecessary, and a locomotive fitted with its own self-contained unit will be free to pass over to any section of the line, and not be tied, as now, to the main source of pulverised fuel supply.

It is not always an easy matter to convert existing hand-fired locomotives to pulverised coal firing, because of the confined and sometimes awkward shape of the firebox, due to the position of the rear or driving-wheel axles, and to the under gear of the locomotive. The space beneath the firebox should be as open and free as possible, thus leaving room for extending the firing area, permitting ready access to the slag-pan, and affording adequate space for the burner equipment.

Mistake is frequently made in converting an unsuitable type of engine to pulverised coal firing, and, in consequence, unsatisfactory results are obtained. The whole question of the use of pulverised fuel for locomotive boiler firing is then condemned out of hand, whereas, had a suitable type of locomotive been selected for test, the results would have proved that considerable economy and advantages could be effected by the conversion.

In view of the restricted area of a locomotive firebox, the cubic area recommended for combustion of fuel in other applications cannot be provided. It is, therefore, necessary to make special arrangements when designing the combustion chamber baffles or fire arch of a locomotive, so that efficient combustion can be obtained by means of these special arrangements. It has been found practical to work down as low as 5 cu. ft. of area per lb. of fuel burned per minute, and to allow as high a velocity of products of combustion as 75 ft. per second. The reduction of combustion area to this limit, and the high velocity of the gases travelling through the fire tubes, is very liable to produce " honeycombing," especially when fuel containing readily fusible ash is used. " Honeycombing," such as that shown in the illustration, cannot be prevented under certain circumstances, and has never yet been entirely eliminated, although with properly designed firebox and equipment this trouble need present no really serious difficulty.

The Huwyler Smoke-Prevention Device.

The Huwyler smoke-prevention device for locomotives has been widely adopted on the continental railway systems for hand-fired locomotives. This is illustrated in Figs. 204, 204*a*, *b*, and *c*. A jet of superheated steam is introduced into the firebox above the ordinary grate, and, expanding, forms a blanket of steam, by means of which the products of combustion are forced back on to the hot fire instead of passing straight to the boiler tubes. At the nozzle end of this steam cone or blanket the products of combustion can pass by at each side of the nozzle, on account of the rectangular shape of the firebox, but by this time the unconsumed carbon in the form of smoke has become burned by contact with the hot fire. The unconsumed carbon, smoke and soot, is either burnt, or is " scrubbed " out; thus only clean gases pass through to the smoke stack. In the writer's opinion such a method would possibly be effective for extracting the fine particles of ash in products of combustion when

Fig. 204.—Smoke Consumer "Off."

Fig. 204*a*.—Four Seconds after Smoke Consumer Started.

Fig. 204*b*.—Eight Seconds after Smoke Consumer Started.

Huwyler Smoke Consumer—Photos taken at Intervals of Four Seconds.

Loco and Auto Economy Accessories, Ltd.]

[*To face p.* 348.

pulverised coal is applied, and may well help to solve the difficulty of "honey-combing." The photographs reproduced in Figs. 204, 204*a*, 204*b* were taken at four seconds intervals. The first view shows smoke emission when the smoke-prevention device is not used.

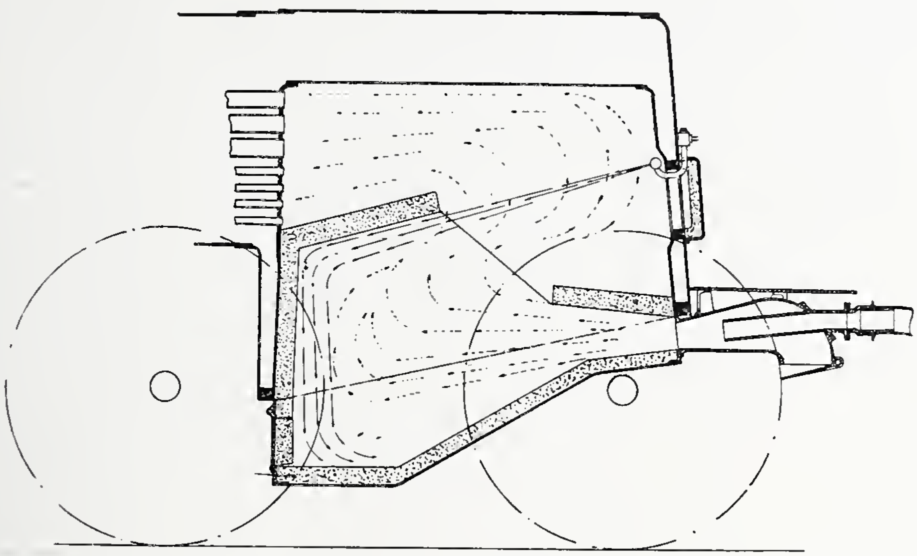


Fig. 204*c*.—Huwyler Smoke Consumer as applied to Pulverised Coal Fired Locomotive, showing action of the Blanket of Superheated Steam above Smoke Zone.
(*Loco and Auto Economy Accessories Co., Ltd.*)

Various Grades of Fuel used on American Locomotives.

Some analyses of different kinds of coal which have been pulverised and applied in this form, for the purpose of making locomotive firing tests on American railways, are reproduced below from published records :—

Chicago and North-Western Railway.

Contents.	Illinois Bituminous.	Kentucky Bituminous.	North Dakota Lignite.
	Unwashed Screenings.		
Moisture	3·18% to 15·36%	1·9% to 2·8%	1·8%
Volatile	Average 34%	36·0%	47·25%
Fixed carbon	Average 47%	54·0%	40·91%
Ash	Average 10%	8·0%	9·32%
Sulphur	Average 1·70%	0·79%	0·72%
B.Th.U.	10,720 to 12,400	13,964	10,960
Fineness :—			
Through 100-mesh	90·7% to 99·69%	93·0%	98·0%
Through 200-mesh	71·45% to 97·06%	83·0%	95·9%

New York Central Railway.

Contents.	Pennsylvania Bituminous. Run-of-mine.					Brazil, South America, Bituminous. Run-of-mine.		
	%	%	%	%	%	%	%	%
Moisture	0·72	0·95	0·51	0·88	0·67	7·90	9·15	1·73
Volatile carbon	28·75	30·85	31·25	35·67	21·63	28·04	29·42	9·50
Fixed carbon	62·51	59·80	59·17	63·05	65·16	34·73	38·29	60·50
Ash	8·94	9·35	9·59	10·40	13·21	29·33	23·14	28·27
Sulphur	2·49	2·30	2·21	1·64	1·51	3·16	2·61	9·1
B.Th.U.	14,096	13,773	13,804	13,912	13,671	8,820	10,080	10,177
Fineness :—						%	%	%
Through 100-mesh	From 88·0% to 96·5%					99·8	99·8	99·8
Through 200-mesh	From 66·5% to 96·6%					96·6	96·6	96·6

The Delaware and Hudson Co.

Contents.	Pennsylvania Anthracite. Waste Trailings from Culm Banks.			Pennsylvania Bitumen. Run-of-mine.		
Moisture	Average 0·50%			Average 0·50%		
Volatile carbon	,, 8·30%			,, 33·0%		
Fixed carbon	,, 72·09%			,, 57·50%		
Ash	,, (12% to 22%) 16·50%			,, 9·0%		
Sulphur	Average (0·66% to 1·97%) 1·00%			Average 2·0%		
B.Th.U.	,, 12,000			,, 13,750		
Fineness :—						
Through 100-mesh	98·7%	100·0%	99·68%	98·1%	100·0%	98·46%
Through 200-mesh	75·3%	85·6%	92·41%	77·0%	86·5%	89·37%

Analyses of Coal Used on Lehigh Valley Railway Express Locomotive.

Anthracite Silt.	%.	Soft Coal.	%.
Moisture	2·26	Moisture	1·9
Volatile	10·39	Volatile	36·59
F.C.	49·30	F.C.	49·89
Ash	38·42	Ash	11·6

Successful steaming has been obtained with various mixtures of these two grades of coal, such as 55 % anthracite and 45 % bituminous coal; 25 % anthracite and 75 % bituminous; $58\frac{1}{2}$ % anthracite and $41\frac{1}{2}$ % bituminous. These figures tend to show that at least a 50–50 mixture can be used for boiler firing on express locomotives.

The Fuller Locomotive Equipment.

The locomotive equipments that have been fitted on American locomotives are the Fuller and the Lopulco units.

The Fuller equipment, shown in Figs. 195, 200, and 201, is a compact self-

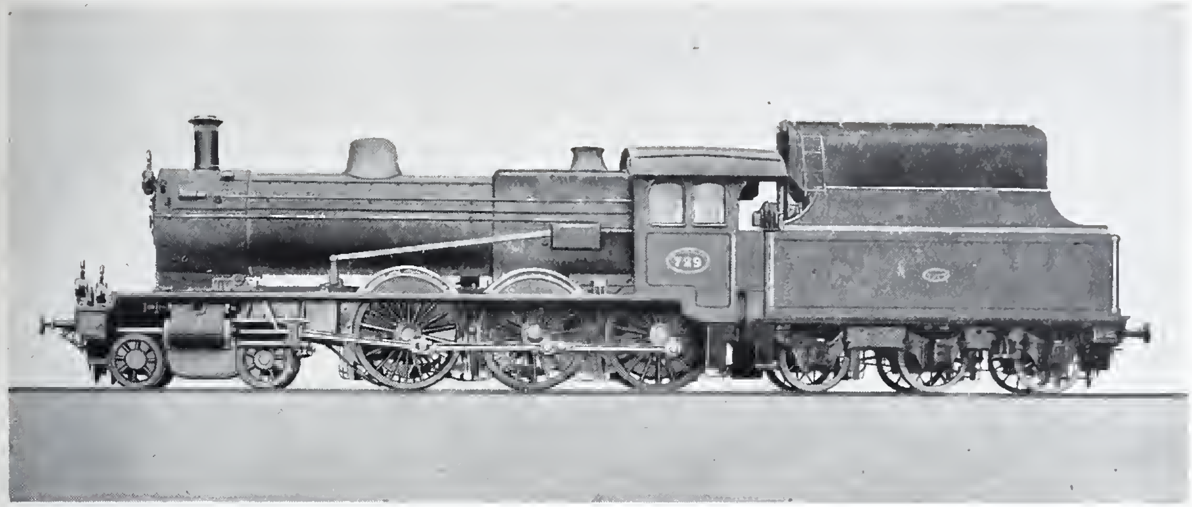


Fig. 205.—Netherlands State Railway Locomotive as Fitted for Burning Pulverised Coal.

The Fuller Engineering Co.] *[The Fuller Lehigh Co.*

Fig. 206.—Switch Locomotive Equipped for Burning Pulverised Fuel.

The Fuller Engineering Co.] *[The Fuller Lehigh Co.*

[*To face p.* 350.

contained unit, and has been designed to facilitate the fitting of these equipments to ordinary locomotives, and to render the whole apparatus accessible and easy of repair by semi-skilled men. As a rule, few changes are required in the firebox, the standard brick arches being used, and the velocity of gases passing through the combustion chamber being kept as low as possible by employing a low-pressure air supply.

The two screw feeders can be controlled by cab regulation of steam to the driving engine up to 300 %, and, by alteration of the gear clutch, regulation up to 600 % is obtainable. Each feed screw is capable of delivering the full quantity of fuel, if necessary, and normally runs at about 260 r.p.m., taking 2 h.p. for the two feed screws. Either feed screw can be operated up to 800 r.p.m. by the vertical steam engine, when required.

Preliminary air is supplied by the turbo fan, the secondary air by a propeller type fan fitted under the tender apron and operated by belt from the turbo fan shaft.

A brief specification of the locomotive equipments supplied by the Fuller Engineering Co. of America is given below :—

Special cast-iron coal-hopper base to receive duplex feed screws. Vertical marine type steam engine for operating same, with intermediate connections, including gears, gear shafts, shafting, etc.

Steam-turbine-driven fan for conveying the coal dust from the feeder to the tender.

Flexible steam connections between engine and tender, as well as flexible connections for transporting the pulverised coal between engine and tender.

Burner with necessary dampers and connections for operating same.

3000° F. pyrometer for indicating firebox temperatures. Electric revolution counter for indicating speed of engine driving coal-feed screws. Revolution counters for each pair of feed screws, gauges and valves for operating this equipment.

Mechanism for operating the slag-pan or slag-pans, as well as mechanism for operating the air dampers in the sides of the combustion chamber beneath the firebox.

There is no great difference in the cost of Fuller equipments for small or large locomotives. The standard equipment can be readily changed, if desired, from one locomotive to another. The only alteration usually required is to change the relation between the engine and feed screws, so that more or less coal can be delivered, according to the size of the locomotive. The equipment will satisfactorily feed from 1000 to 8000 lb. of coal per hour without change in the main details. As will be seen from the illustrations, the whole equipment is very compact, yet accessible, and, as a rule, it is not necessary to make extensive alterations to the locomotive or tender in order to attach the equipment.

The equipment is started, and the coal supply commenced, with a steam pressure of from 20 to 30 lb., which could hardly be done with a steam-turbine-driven unit. The main difference in cost of equipment for a large or small locomotive is mainly governed by the size of the coal tank. This is usually built in the railway shops, and the size of the tank is based upon the weight of the pulverised

coal, about 35 lb. per cu. ft., $\frac{3}{16}$ in. sheet-iron plates are used for constructing the tank. The cast-iron hopper base in which the feed screws operate forms a solid base both for the coal tank and feeder screws, engine, gears, etc.

Railroad authorities usually find it advisable, and less costly, to construct the coal tanks in this manner, and to carry out the alterations necessary to provide for the combustion chamber (occupying approximately the same space as is taken up by the existing ash-pan) and the slag-pan, or pans, which go beneath the combustion chamber. All firebrick for arches and combustion chamber lining can also be found locally, as a rule.

A Netherlands State Railway locomotive constructed in this manner and equipped with Fuller pulverised coal burners is shown in Fig. 205.

Return arches or large locomotives are supported on water-tubes in the firebox, but for the smaller locomotives it is a practical method to support an arch on studs secured in the side of the firebox, a course adopted for small locomotives, such as the switching locomotive illustrated in Fig. 206.

The Lopulco Locomotive Equipment.

The Lopulco equipment, Fig. 207, consists of a number of items separately mounted upon brackets or supports and protected in sectional casings as shown. The whole arrangement is therefore by no means so compact or convenient for fitting on the locomotive as the Fuller self-contained unit. Three screw feeders, as a rule, are used, each supplying fuel to a separate burner. A steam turbo is provided for operating the feeder screws. This has a range of regulation of about 100 % by alteration of steam supply thereto, and the variable speed governor supplied. Additional regulation of speed up to 300 % is effected by shafting the gear clutch. The blower for supply of primary air is of the centrifugal type, driven by steam turbo, and delivers air at about 6 in. or 8 in. water gauge pressure to the fuel through the curved bends shown in Fig. 207. Additional air is admitted by means of hand-regulated dampers fitted at the combustion chamber.

Tests on Lehigh Valley Railway.

Some very interesting and practical tests were made in April and May 1920 with the Fuller equipment to ascertain the fuel consumption on two standard freight locomotives on the Lehigh Valley Railroad, U.S.A. (see Fig. 197). The section of line selected was between Easton and Packerton and return, a round trip of 87·4 miles. One locomotive was arranged for hand firing and the other fitted with a Fuller equipment for burning pulverised coal.

The pulverised coal was accurately weighed in the tank on tender each time the locomotive took on coal, proper correction being made for any water consumed between the times the locomotive went over the scale. The total weight of coal consumed was, therefore, determined within a few pounds, and an accurate record was also kept of the total revolutions made by the feed screws from coaling period to coaling period, thereby obtaining a calibration of the feed screws for each individual run. In order to preclude any possibility of error due to different weights and densities of the coal, the calibration was corrected for every round trip. By

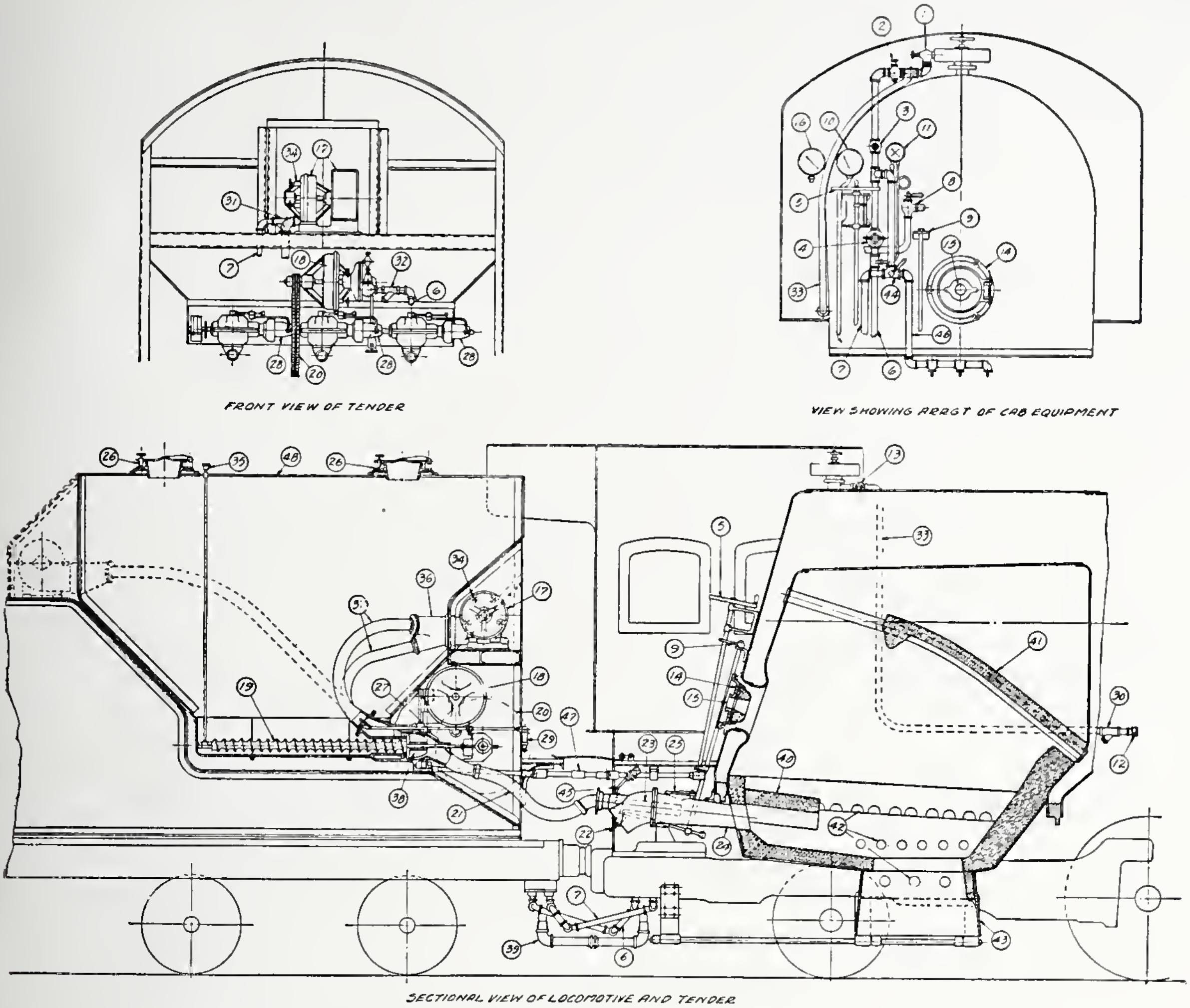


Fig. 207.—Lopulco Pulverised Coal Equipment for Locomotives.

(*General Electric Review.*) (*Combustion Engineering Corporation.*)

1. Turret valve.
2. Pressure reducing valve.
3. Cutout valve.
4. Emergency regulating valve.
5. Feeder control wheel.
6. Steam line to feeder turbine.
7. Steam line to turbo-blower.
8. Stack blower valve.
9. Operating handle for damper 22.
10. Speed indicator for turbine 18.
11. Duplex steam gauge for steam lines 6 and 7.
12. Firing up steam coupling.
13. Firing up steam valve.
14. Fire door.
15. Peep-hole.
16. Boiler steam gauge.
17. Turbo-blower.
18. Feeder turbine.
19. Fuel feed screw
20. Driving gear.
21. Fuel hose.
22. Induced air damper.
23. Fuel nozzle.
24. Burner.
25. Burner hand hole cover.
26. Fuel filling hole cover.
27. Feeder hand hole cover.
28. Feeder clutches.
29. Feeder clutch operating handle.
30. Steam strainer for firing up line 33.
31. Steam strainer for turbo-blower line 7.
32. Steam strainer for feeder turbine line 6.
33. Firing up steam line.
34. Turbo-blower nozzle valve.
35. Grease cup for feed screw.
36. Pressure blower manifold.
37. Pressure blower conduits.
38. Fuel and air commingler.
39. Exhaust steam line.
40. Primary arch.
41. Security arch.
42. Auxiliary air inlets.
43. Slag pan.
44. Three-way valve.
45. Steam nozzle.
46. Steam nozzle pipe.
47. Flexible connection.
48. Pulverised fuel container.

these precautions the accuracy of fuel registration was confined to an error of $\frac{1}{1000}$ lb. per revolution.

The coal consumed by the hand-fired locomotive was a mixture of 50 % run-of-mine bituminous and 50 % pea coal. The fireman used his own discretion as to whether he would use more bituminous coal or more pea coal, the condition of the fire being the determining factor. No accurate record was, therefore, available as to the quantities of these two grades actually used.

The coal consumed by both locomotives includes all the coal from the time locomotives left Easton with their trains until they cut off from the train on arrival at the terminal point on the return trip.

The cost of the coal delivered to the two locomotives was based on the following figures :—

Bituminous coal . . .	$2·50	per ton of 2000 lb. at the mine.
Freight to Easton . . .	2·28	,, ,, ,, ,, ,,
Pea coal	4·50	,, ,, ,, ,, ,,
Freight to Easton . . .	1·10	,, ,, ,, ,, ,,
Raw anthracite silt . . .	0·50	,, ,, ,, ,, ,,
Freight to Easton . . .	1·10	,, ,, ,, ,, ,,

Cost for handling coal from cars on to tender of hand-fired locomotive, 20 c. per ton.

Cost for handling coal from cars on to tender of pulverised coal-fired locomotive, including handling, drying, and pulverising, 40 c. per ton (for the mixture of 52·5 % anthracite silt and 47·5 % bituminous coal).

Cost for handling the straight bituminous, 36 c. per ton (the above charge includes also the interest on investment in the pulverising plant, taxes, insurance and depreciation).

Because the crown sheet of the pulverised coal-fired locomotive was very low—about 10 in. above the top of the fire door—it was found necessary, after making a few runs, to shorten the height of the brick arch to seven-brick instead of nine, by reason of the restricted space between the top of the arch and the crown sheet, and also because of the effect of the excessive heat on the crown bolts directly over the top of the arch. This locomotive had no arch originally, and it was extremely difficult to place one because of the flat, shallow firebox, which entailed some very sharp bends in the arch tubes.

The stack exhaust nozzles (two) were originally $3\frac{1}{2}$ in. in diameter each. These were removed entirely, right from the first day the pulverised coal-fired locomotive went into commission, and the locomotive ran throughout the trial with a free, unobstructed exhaust opening. This tends greatly to soften the sound of the exhaust and removes back pressure on the cylinders. No trained crew was assigned to this locomotive, and a different engineer made the run on practically every trip. The locomotives employed on these tests were of the following specification :—

Cylinder	20 in. × 26 in.
Pressure	175 lb.
Drivers	63 in.
Weight	157,675 lb.
Heating surface	1901 sq. ft.
Firebox	119 in. × 82 in.
Nozzles	(No. 1360—4 in. dia.)
Double	(No. 1372—3½ in. dia.)

A mixture of run-of-mine bituminous coal and anthracite pea coal was used for hand firing, anthracite silt being substituted for pea coal for the pulverised mixture thus :—

Hand Firing.	Pulverised Coal.
50% Anthracite pea.	52·5% Raw anthracite silt.
50% R/M bituminous.	47·5% R/M bituminous.

100% Bituminous was also used in pulverised form.

Summary of Results.

	Hand Firing. Bituminous and Anthracite pea coal.	Pulverised Coal. Bituminous and Anthracite silt.	Straight Bituminous coal.
Ton miles per round trip	145,628	126,829	147,130
Coal per round trip	17,696	19,034	16,960
Coal per 1000 ton miles (lb.)	121·95	150	115·3
Cost of coal delivered on tender per ton	$5·16	$3·51	$5·14
Cost of fuel per round trip	$40·71	$29·84	$38·96
Saving per round trip	—	$10·87	$1·75
Per cent. saving	—	26·7%	4·3%
Cost per round trip, including coal used at terminal	$44·17	$30·78	$40·30
Saving per round trip	—	30·3%	9%

Some of the actual total figures recorded are set out below, and, in comparing the fuel consumption for hand firing and pulverised coal firing, due regard must be given to the difference in quality and, therefore, the calorific value of the actual coal mixtures used.

Hand-Fired Locomotive.

50% Anthracite Pea Coal. 50% Bituminous Coal.

	Miles.	Ton Miles.	Lb. of Coal.	Lb. of Coal 1000-ton Miles.
Easton to Florence, Slatington and Packerton	43·7	40,051	9,504	237
Packerton to Bethlehem and Beldel	45·2	115,205	8,112	70·4
Total for round trip	88·9	155,256	17,616	113·5
Easton to Richards, Reddington and Packerton	43·7	44,871	11,312	253
Packerton to Slatington, Richards and Florence	43·7	91,130	6,464	71
Total for round trip	87·4	136,001	17,776	130·4

Average : 121·95 lb. of fuel per 1000 ton miles.

PULVERISED COAL-FIRED LOCOMOTIVE.

100% Bituminous Coal.

	Miles.	Ton Miles.	Lb. of Coal.	Lb. of Coal 1000-ton Miles.
Easton to Florence, Allentown and Packerton	43·7	42,253	11,054	262
Packerton to Philipsburg	44·2	110,633	6,792	61·4
Total for round trip	87·9	152,886	17,846	117
Easton to Richards, Slatington and Packerton	43·7	41,049	9,113	221·5
Packerton to Richards	40·7	100,325	6,961	69·5
Total for round trip	84·4	141,374	16,074	113·6

Average: 115·3 lb. of fuel per 1000 ton miles.

PULVERISED COAL-FIRED LOCOMOTIVE.

52·5% Anthracite "Silt." 47·5% Bituminous Coal.

	Miles.	Ton Miles.	Lb. of Coal.	Lb. of Coal 1000-ton Miles.
Packerton to Florence	34·2	71,375	6,629	93
Easton to Packerton	43·7	45,967	9,548	207·6
Total for round trip	77·9	117,342	16,177	137·5
Packerton to Collay and Beldel	45·2	89,903	8,273	92·1
Easton to Kokendauqua and Packerton	43·7	36,726	10,761	293·5
Total for round trip	88·9	126,629	19,034	150

Average: 143·75 lb. of fuel per 1000 ton miles.

The foregoing test figures show that the pulverised coal-fired locomotive burned 115·3 lb. of coal per 1000-ton miles, when fired with straight bituminous coal, and 143·75 lb. of coal per 1000-ton miles, when fired with a mixture of 52·5 % anthracite "silt" and 47·5 % R/M bituminous, as against 121·95 lb. of coal per 1000-ton miles for hand firing with a mixture of 50 % anthracite "pea" coal and 50 % R/M bituminous.

Due to the difference in cost of these various fuels delivered on the tender, the cost of the fuel per round trip for hand firing was \$40·71, while the cost of the pulverised fuel (100 % bituminous) was \$38·96 and (52·5 % to 47·5 % mixture) \$29·84 per round trip. This shows a fuel cost saving per round trip with bituminous coal of \$1·75, or 4·3 %, and a fuel cost saving with mixed fuel of \$10·87 or 26·7 %, of the cost of coal for hand firing, notwithstanding the fact that more fuel was used

as a mixture in pulverised form than was used in this manner for hand firing. The anthracite "silt," however, could not have been used in any other manner.

Additional benefits, which must not be overlooked, are: the entire elimination of ash-pits, and the time lost in cleaning fires when locomotives are hand or stoker fired; the ease with which the largest locomotives can be fired with pulverised fuel, and the ability to burn the cheapest and poorest grade of coal and keep the engine hot. Further important points are that the anthracite "silt" burnt contained 35 % to 38 % ash and a B.Th.U. value of only 9675. It is only necessary to take in fuel once during a round trip instead of twice, as with the hand-fired locomotive, and, with a terminal in which proper provisions are made, the tender could be coaled at the same time that the tank is filled with water, thus further eliminating idle time. All front end netting and its maintenance are eliminated, and inspection of grates, grate bars, or repairs thereto are unnecessary when pulverised coal is used.

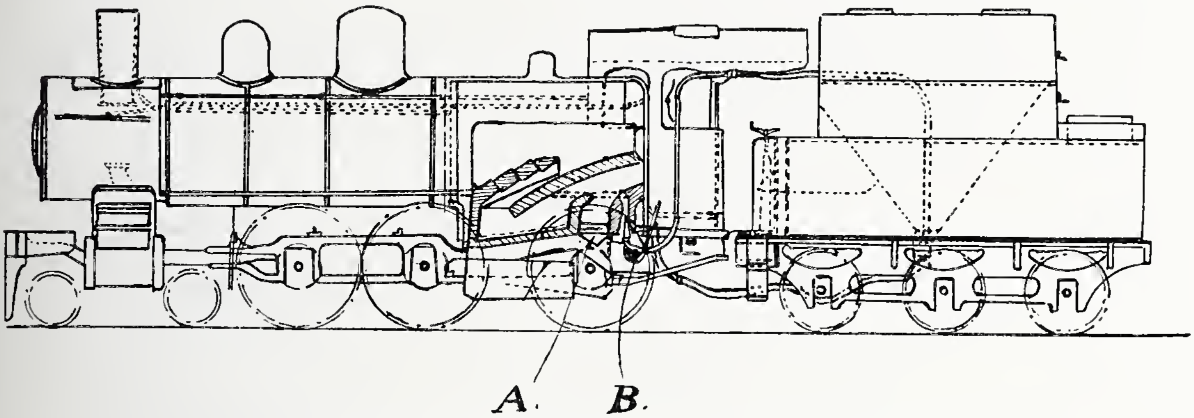


Fig. 208.—Locomotive for Burning Pulverised Peat on Swedish State Railways.
A. Auxiliary Coal Grate. *B.* Pulverised Fuel Burner.

Pulverised Peat as a Locomotive Fuel in Sweden.

As previously mentioned, peat has been used as a locomotive fuel with a certain amount of success in Sweden. An excellent article by Bureau Engineer, Carl Flodin (Centraltrychkerier, publishers, Stockholm, 1916), includes full data regarding tests conducted upon peat-fired, eight-coupled freight locomotives: tractive power 9000 kg.; weight 51,000 kg.; tender 36,000 kg.; water capacity of tender 14,000 kg.; pulverised peat 4000 kg.

Fig. 208 shows the arrangement of firebox with auxiliary coal-burning grate, as adopted for the burning of pulverised peat on these locomotives.

Tests were carried out in November, 1915, and it was then found that, for equal boiler duty, 1 kg. of coal was equal to 1·45 kg. of pulverised peat, the coal used having a calorific value of 7240 cals. and the peat as used 4400 cals., or approximately 13,000 and 7900 B.Th.U. per lb.

The arrangement of the firebox setting allowed for a small grate on which coal was burnt under the incoming mixture of powdered peat and air. On this small hand-fired grate 3 to 4 kg. of coal were consumed per 100 kg. of peat; the analysis of peat and coal was as follows :—

	Powdered Peat. %	Coal. %
Carbon	47·0	73·5
Hydrogen	4·5	4·4
Oxygen	29·5	8·6
Sulphur	0·5	1·5
Nitrogen	1·1	1·2
Ash	3·2	6·2
Moisture	14·2	4·6
	100·0	100·0

Analagous tests made with coal-fired and powdered peat-fired locomotives gave the following overall boiler efficiencies and firebox temperature of gases :—

	Efficiency %.	Temperature.
Hand coal-fired	65	1510° F.
Pulverised peat-fired	75	1670° F.

Recorded and corrected figures for parallel trips with coal- and peat-fired locomotives are given by this writer in his paper; the more important of these figures have been extracted and tabulated below :—

RESULTS OBTAINED ON COAL (HAND-FIRED) AND PULVERISED PEAT-FIRED LOCOMOTIVES ON THE SWEDISH GOVERNMENT RAILWAYS.

Parallel Test Run.	Trip Number.	Weight of Loco., Tender and Wagons.	Wagons.	Average Speed, Km/Hr.	Consumption in Kg. of Fuel per 1000 metric tons per km. 1000 kg. Inclusive Loco. and Tender.	Smoke-box Temp.	Kg. Steam per Kg. Fuel.
		Ton/1000 kg.	Ton/1000 kg.			°F.	
A. Freight service.	1. Pulverised peat	787	700	29·2	37·5	255	4·69
	2. Coal	782	700	27·5	25·6	290	6·83
B. Freight service.	3. Coal	782	700	28·7	27·7	312	6·55
	4. Pulverised peat	787	700	27·0	40·7	294	4·77
C. Passenger service.	5. Pulverised peat	387	300	42·3	56·9	289	4·67
	6. Coal	382	300	41·7	39·0	268	7·05

With the 4000 kg. of peat fuel taken on board, the locomotive pulling a 650-ton freight train or a 300-ton passenger train, it was found that these quantities of fuel on the section of the line in question, and at the average train speed mentioned, would be sufficient respectively for a 100- and 130-km. run.

From 3 tons of air-dried turf, 2 tons of peat powder are obtained. The peat powder contains 12 to 16 % of moisture, is non-explosive and non-hygroscopic. It can be stored for long periods without fear of spontaneous combustion. The only effect of the high percentage of moisture is that it is necessary to employ a small hand-fired coal grate to ensure continuous ignition of the fuel and evaporation of the moisture.

Outstanding Advantages of Pulverised Peat.

On this matter of the use of peat-dust fuel in Sweden on the Swedish State Railways, Dr. P. Wangemann, engineer, Radolfzell, has referred to this matter in a lecture, and makes the following remarks thereon :—

In America, the difficulties attaching to dust firing have been removed by increased drying and finer grinding; in Sweden the opposite path has been followed, and burners for coarser material and a greater percentage of moisture have been resorted to. This contradiction is extremely interesting and instructive. Both methods have been successful. The American method, of higher drying and finer grinding, has the advantage of superior technical perfection and of greater efficiency, but against this there is the greater cost of plant and working in connection with drying and grinding, and the more arduous work of stoking with the coal dust. The Swedish method has the advantage of the more primitive but more reliable firing for working, less expenditure in the treatment of the fuel, the better condition for transport of the dried and ground material, the much reduced danger of explosions, and, above all, the non-hygroscopic condition of the material itself.

The essential and outstanding feature, as compared with the American method, consists in this, that not actually dust, but comparatively coarse powder is manufactured, all passing through 100 meshes per square centimetre, as compared with the minimum 900 meshes of American practice. Then, again, fuel is only dried to 12 to 16 % of moisture, as compared with 1 to $1\frac{1}{2}$ % in the American method.

At all events, the Swedish peat powder has the advantage that it is non-explosive, that it gathers practically no moisture during storage and transport in covered stores and wagons, that it does not lose its characteristic dryness, that it can be loaded and transported in a very simple manner, without requiring any special safety measures. A small test, made by taking a tumbler full of water, throwing therein a certain quantity of peat powder, and then turning the glass upside down and shaking the contents, barely reveals an increase of moisture of $\frac{1}{3}$ %. This property, which is perhaps a special feature with peat, has its analogy in the small absorption of moisture by air-dried peat blocks.

Swedish State Factory (The Ekelund and Porat Peat Processes).

The first State peat-dust factory for the supply of fuel to locomotives was started in 1919. This factory has a capacity of 20,000 tons of peat powder per annum. In the preparation of the peat, which is delivered to the works in semi-dry state containing from 25 to 40 % of moisture, the fuel is first dried to from 12 to 16 % of moisture, below which point it is not reduced. The pulverised peat passes a screen having 100 meshes per sq. cm., and is made from the fines extracted from the bulk. Coarse fibrous material, 3 to 8 % of the bulk, is removed by sifting, and is not pulverised, this portion of the peat being used for textile work in the making of a wool-like fabric. The following notes have also been taken from the writings of Dr. Wangemann.

Two methods are in use in Sweden; one is the Ekelund and the other the Porat method. The former is used in the Vislanda State Factory, and in connection with very shallow and very high ovens about 10 metres high. The sieved peat dust is

fed from the top with a percentage of moisture of from 25 to 40, and flows downwards through a series of zig-zag baffles, while the hot-air stream travels in the opposite direction—that is, from the bottom to the top.

The process of producing peat powder by Porat's method differs essentially from that of Ekelund, by the use of a drum dryer, instead of the high stage-kiln, and also by the wide regulation of cool air and heating gas.

We now come to the most ticklish point in the making of peat powder. In order to ensure good combustion it is necessary, in view of the high percentage of moisture up to 16 % and the coarseness of the material, that the light constituents of the powder should keep together, as otherwise it would be difficult to keep the flame going with the primitive burners used in Sweden. In order to keep these light constituents in powder form, it is necessary to secure the correct temperature regulation, whereas, on the other hand, the current of cool air carrying the moisture away can hardly be reduced. These " tricks " are, of course, a matter of experience, and the secret of the inventor. As already known, Herr Porat has transferred his rights for making peat powder to a newly formed Berlin syndicate, who have undertaken to exploit the process for making peat powder in Germany, Austria, Hungary, Switzerland, Italy and Holland. (The company has been formed under the title of " Staubfeuerung G.m.b.H," with offices at 31, Linkstrasse, Berlin.)

The Vislanda works produce 75 tons of peat powder with a maximum of 16 % moisture per day; the average contents in moisture should be 12 %. The turf delivered contains from 25 to 40 % of moisture. The total output of the Vislanda works is 20,000 tons, and suffices for feeding 35 to 45 locomotive engines continuously. The machinery at the works comprises : 1 breaking machine, 2 disintegrators, 3 mills with fine sieves. The machines are designed for an hourly capacity of $3\frac{1}{2}$ tons of prepared material, 10 % of which is waste. The power required is 25 h.p. According to experience, 1 cu. metre of peat, or $\frac{1}{3}$ ton, produces 47 kw. hrs. for the work of transport, breaking, disintegrating, sieving, oven-charging and fine grinding. In addition, 100 kw. hrs. are required for bringing the material from the turf-pit to the storage building per ton, which has to be considered if the power is also applied to the work on the marshes. According to experience, from 3 to 5 kg. of peat at 25 % moisture are used per kw. hr. At Vislanda, eight men and one works superintendent are required for the work at the factory, exclusive of the work on the marshes, but including the bringing of the turf blocks from the various storage places, which are scattered far apart.

Porat extracts 2 tons of powder from 3 tons of air-dried turf, so that one-third is waste (roots and fibre used for heating) and represents the loss in drying. With the group of machines in use, 35 tons of turf at 40 % moisture are reduced to 24 tons of peat powder in 24 hours. To run the works Porat requires :—

	Men.
For loading raw peat from storage to factory	4
Breaking machine	1
Generator	1
Air-heating	1
Mill	1
Yard work	1
Total	9

The cost for the year 1915 is available, as it has been worked out by the State Commission, and, according to this record, the cost per ton of producing pulverised peat was :—

Cost of manufacture	13·67 Kr.
Interest and sinking fund	8·08 ,,
	21·75 Kr. per ton.
	= 24s. 6d.

At that time 2·6 tons of raw peat at 51 % moisture were required to produce 1 ton of peat powder at 15 % moisture.

In another factory the cost of producing peat powder amounted to :—

Cost of manufacture	11·60 Kr.
Interest and sinking fund.	5·26 ,,
	16·86 Kr. per ton.
	= 18s. 10d.

The prepared peat dust is conveyed pneumatically to the silos, from which it is removed in special transport vehicles. These vehicles take the dust to the transport silos, where the locomotive engines are supplied.

The tender is fitted with a covered body, the volume of the dust being greater than that of broken coal. Three cu. metres are required per ton.

The tender of one of the types of locomotives holds 4000 kg. of peat powder, with which a goods train weighing 300 tons empty and 650 tons loaded, or a passenger train weighing 300 tons empty, can run 100 to 130 kilo. without renewing its supply of fuel powder.

CHAPTER XVI

CENTRAL DEPOTS FOR SUPPLY OF PULVERISED COAL TO SMALL CONSUMERS, AND SELF-CONTAINED PULVERISER UNITS

Dry Fuel Essential for Public Supply—Central Supply Depots, Cost of Production and Delivery—Pacific Coast Coal Company's Fuel Supply Methods—Small Consumer's Burner Equipments—Self-Contained Pulveriser Units.

In several localities in America there are now commercial companies owning central pulverised coal depots, from which delivery is made daily or as often as may be required to small consumers. The economies to be gained when burning powdered coal in small quantities are as important, in the aggregate, as the savings to be effected in large works. A small consumer may not always be able to instal even a self-contained unit of the " Stroud," the " Aero " or other type of machine now available. His furnaces may be too small individually for the economic application of the self-contained unit. In such cases a Central Supply Company can provide for the needs of the small consumers, both as to the delivery of pulverised coal and the installation of special equipment for applying the fuel to works furnaces or Institution boilers, etc.

Coal can be delivered by rail or road truck wagon and run out into hoppers at the works, or, for smaller quantities, can be supplied as required in steel drums.

In cases where the collective demand is for, say, a number of small industrial works grouped together, pulverised coal can be supplied through underground or overhead pipes by means of the air pressure or pumping systems, just as readily as gas, water or oil are supplied by means of pipes.

In course of time, and when old prejudices have been overcome, the supply of pulverised coal to small consumers may become an important industry, and the saving in fuel resulting therefrom is certainly worthy of consideration.

Dry Fuel Essential for Public Supply.

For burning pulverised fuel in very small quantities it is all the more essential that the fuel should be dry, otherwise clogging up of the burner apparatus or uneven firing may take place. In humid climates reabsorption of moisture by the fuel during the period of transport from the producing station to the users must be prevented by enclosing the fuel in air-tight tanks or drums.

The author has often thought that it might be possible to mix with pulverised coal some fine substance that would prevent to a great extent the reabsorption of moisture from the atmosphere in some relation to the well-known production of table salt. If such a substance could be found of a combustible nature, then a

"non-hygroscopic" mixture of little impaired calorific value could be delivered to small users without fear of the fuel becoming too moist for efficient handling and burning. Pulverised residue coke from distillation plants might conceivably be such a medium.

It so happens that British Patent No. 16978 of 1917, by N. K. H. Ekcland of Sweden, suggests a similar proposal; the following notes (*The Engineer*, February 28th, 1919) refer to this invention :—

Pulverised charcoal or coal is found to be difficult to use as fuel. Both of them are hygroscopic and, owing to their consistency as powder, absorb still more water out of the air than charcoal or coal in a solid form, whereby the risk of spontaneous ignition arises. Such powder, during transport and storage, readily cakes in lumps, whence it is difficult to feed it forward into the furnaces or hearths intended for burning pulverised fuels. By the absorption of water the calorific value is diminished and the powder becomes difficult to light and burn. The present invention is intended to produce from pulverised charcoal or coal a powdered fuel without the drawbacks referred to, and the novelty of the invention consists in the fact that finely ground and thoroughly dried charcoal or coal is mixed with a finely divided and thoroughly dried powder of peat, the peat powder having been exposed, before the close grinding, to an artificial drying at a temperature, for example, of 212° F. By drying the peat powder at a high temperature, the peat particles lose their structure, the peat powder its hygroscopic property, and, in addition, it prevents the pulverised charcoal or coal from absorbing moisture from the air. As moreover peat powder is elastic, it prevents caking and packing into lumps, wherefore it easily allows itself to be used as pulverised fuel in furnaces or hearths. Finally, inasmuch as the peat powder is easily ignited and easily burnt, it forms in the furnaces or hearth chambers a flame by which the pulverised charcoal or coal is ignited and burnt. The proportions of pulverised charcoal or coal and peat powder depend upon the various conditions of the coal and peat, and will vary according to such condition; the smallest quantity of peat in any case will, however, be 10 % by weight.

If this method is found to be a solution of the difficulty referred to, it will be of great value to Pulverised Fuel Supply Companies in many countries.

Central Supply Depots : Cost of Production and Delivery.

The many questions attaching to the distribution of pulverised coal in small quantity to users taking supplies from a central pulverising station cannot be better presented than by referring to the very comprehensive notes written upon this subject by Alonzo Kinyon, combustion engineer, Fuller Engineering Co., U.S.A., and inventor of the Kinyon small consumers' unit illustrated herein. Kinyon has devoted much time and patience to the problem of burning pulverised fuel in small self-contained units, more particularly those adapted for use in connection with house, office and hotel heating installations.

The Kinyon apparatus, which has been designed for small users, is an entirely self-contained pulverised coal-burning apparatus assembled as a single unit, comprising coal-storage reservoir of limited capacity, coal feeder and burner operated

by fractional horse-power motor direct connected to a fan, and taking power, if necessary, from the electric lighting circuit. As a rule, very slight alterations are necessary in the firebox of a boiler or heating furnace, these being confined to the provision of a properly arranged fire-brick lining. For installations burning 1200 lb., or less, per 24 hours, pulverised coal can be delivered in air-tight steel containers, each having a capacity of about 300 lb. The unit is fitted with raising arms, by means of which a steel container can be placed in an inverted position over the hopper, each container thus forming a coal magazine for the unit.

The following estimates have been prepared by Alonzo Kinyon, who advises, for plants burning more than 1200 lb. of coal in 24 hours, that a pulverised coal-storage hopper should be provided into which the pulverised coal can be conveyed direct from the motor supply truck. It is suggested that delivery should be made by special motor trucks consisting of tractors attached to semi-trailers of 10 and 15 tons capacity, the 15-ton trailers being used for coal in bulk, contained in steel hopper tanks, and the 10-ton trailers being fitted with platform bodies for handling the 300-lb. steel containers.

The capacity of pulverising plant should be fixed according to initial requirements, the complete sections being duplicated as the demand increases.

The advantage will not only be one of economy as to the actual amount of fuel used, but one of freedom from the black smoke which is so objectionable, particularly in cities where it is necessary to burn bituminous coal for heating and other purposes. Cleanliness of operation is also a feature, and, due to the automatic thermostat control for the feed of coal to the apparatus, an installation of this sort is practically automatic, requiring no attention other than seeing that the coal is supplied and that the ashes and slag are removed at infrequent intervals.

Central Pulverising Plant Data for 200 tons per 24 Hours.

Necessary Initial Investment.

Milling plant and building complete	$70,000
Office buildings, scales, sheds and incidentals	5,000
Machinery for unloading and handling	7,500
Three motor tractors to handle 15-ton semi-trailers, $6000 each	18,000
Four semi-trailers steel coal-hopper tanks, 15 ton capacity, with coal-pumping equipment for delivery of coal to users' bins, $2,000 each	8,000
Two flat body semi-trailers for delivering coal in 300 lb. containers, $1,000 each	2,000
One thousand steel containers of 300 lb. capacity, $14 each	14,000
Rental of mill per year	2,000
Necessary operating capital to handle 200 tons per day, based on 45 days' turnover	35,000
Total equipment and operating investment	$161,500

Estimated Cost of Handling, Preparing and Delivering Coal to Consumer per Ton.
(Costs based upon actual results)

Cost of coal at the mines per ton (2000 lb.)	\$2·75
Freight per ton	1·18
Unloading per ton	0·10
Depreciation in weight by drying out 7 % moisture from 8 % to 1 %, figuring \$2·75 per ton mine cost, freight \$1·18, and 10 % unloading	0·28
Cost of coal for drying 7 % moisture, 6 lb. water evaporated per lb. of coal burned, and coal at \$4·05 per ton	0·047
Power for pulverising and drying and operating conveyors at $1\frac{1}{2}$ c. per kw. figuring on 15 kw. consumption per ton of output . .	0·225
Mill labour : Miller at 5 c. per hour ; Dryer fireman at 40 c. per hour ; Common labour 35 c. per hour ; Three shifts of 8 hours each—3 men on a shift—that is, one miller, one fireman, and one labourer . .	0·15
Repairs and depreciation	0·07
Filling hopper truck and loading containers and placing same on trucks	0·10
Total for supplying and preparing coal and placing same on trucks for delivery	\$4·90

Cost of Delivery.

Labour : Truck drivers and helpers.

Drivers at 55 c. per hour; helpers at 45 c. per hour, driving with radius of five miles from plant.

Average speed of trucks figuring at 10 miles per hour with 60 mins. to load and 60 mins. to unload 15-ton tank truck, and 2 hours to load and 2 hours to unload 10-ton truck-handling steel containers.

Assuming that 150 tons of daily output is delivered in bulk by means of 15-ton truck trailers, would mean 10 trips of 1 hour running time each, or 10 hours and 10 loading and unloading periods of one hour each, or a total of 20 hours.

Allowing another 4 hours for incidental delays, would mean 24 hours' labour for two men, one at 55 c. per hour and one at 45 c. per hour, to deliver 150 tons of coal, or at a total cost for delivering per ton . . . . \$0·16

Assuming that 50 tons of daily output is delivered in 300-lb. containers, would require 5 trips of the 10-ton trailers of 1 hour running time, or 5 hours and 5 periods of loading and unloading of 2 hours each, or 10 hours, making a total of 15 hours to deliver

50 tons at 55 c. for one man and 45 c. for helper, making the cost for delivering coal per ton in steel containers . . .	0·30
Assuming that coal will be delivered in a district not exceeding 5 miles from a central pulverising station, the cost for gasolene and oil for operating the motor trucks, figuring gasolene at 25 c. per gallon and lubricating oil at $1 per gallon, would be . .	0·04
Grand total of cost per ton delivered to consumer (exclusive of Company's profits)	$5·40

Operating Costs.

Salary business manager, per year	$6,000
Plant superintendent, per year	3,000
Four clerks at $80 per month, per year	3,840
Incidental office expenses, rent, light, heat, stationery, etc. . .	4,000
Interest on investment of $161,500 at 6 %	9,690
Depreciation on equipment not included in 7 c. per ton charges for preparation facilities, investment amounting to $54,500 at 10 %, or a total of	5,450
Making a total overhead cost per year of	$31,980

Annual Output of Plant.

200 tons of coal for 8 months' heating, season of 240 days .	48,800 tons
100 tons of coal for 4 months' non-heating, season of 121 days .	12,100 ,,
Total output per year	60,900 ,,

Profits to Central Pulverising Plant.

60,900 tons at $1·20 per ton profit		73,000
Less operating cost of	31,980	41,115
Less, say, 15 c. per ton royalty	9,135	
Making a total profit per year of		$31,885

which gives a return on the investment $\frac{31,885}{161,500}$, or 19·743 %.

By the substitution of lower grade or cheaper slack coal in place of the run-of-mine coal, profits can be increased.

Pacific Coast Coal Company's Fuel Supply Methods.

B. J. Cross, of the United States Bureau of Mines, has also described the methods adopted for the supply of pulverised coal by road and railway truck service from the Pacific Coast Coal Co.'s works at Seattle, Wash., U.S.A., and the following extracts are reproduced from *The Colliery Guardian*, Sept. 7th, 1920 :—

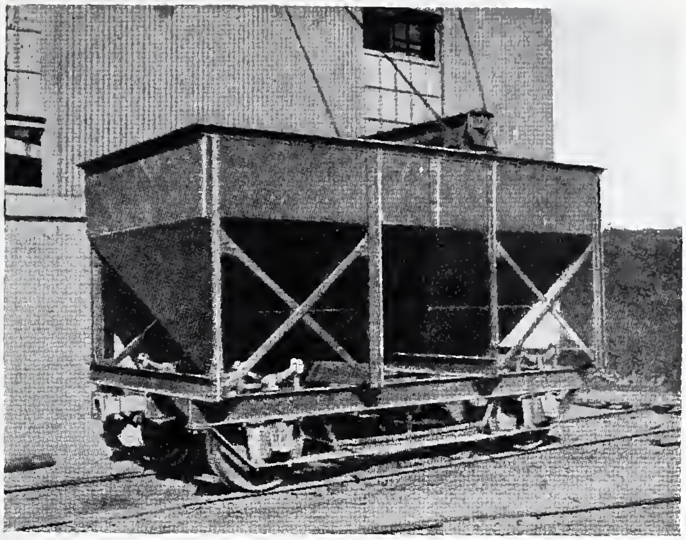


FIG. 209.—INTER-DEPARTMENTAL PULVERISED COAL DELIVERY TRUCK FITTED WITH DUST-TIGHT DISCHARGE GATES.

Quigley Fuel Systems, Inc.]

FIG. 210.—PACIFIC COAST COAL CO.'S MOTOR ROAD TRUCK FOR DELIVERY OF PULVERISED COAL.

[*To face p.* 366.

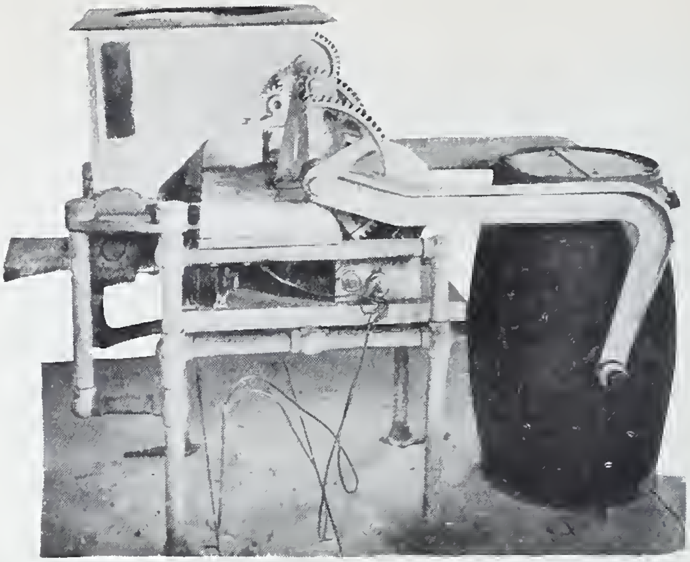


FIG. 211.—KINYON SMALL CONSUMER'S EQUIPMENT WITH FUEL CONTAINER READY FOR LIFTING.

The Fuller Engineering Co.] [*Alonza Kinyon.*

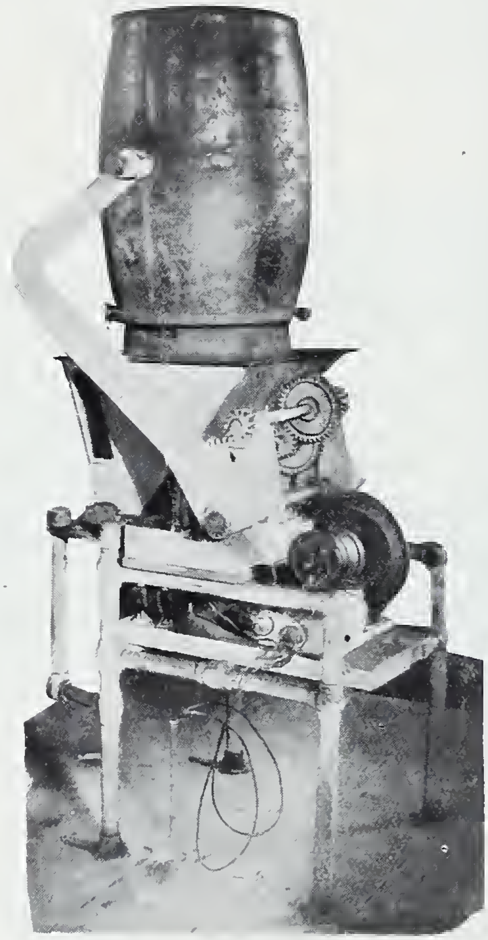


FIG. 212.—KINYON SMALL CONSUMERS' EQUIPMENT WITH FUEL CONTAINER IN POSITION.

The Fuller Engineering Co.]

The pulverised coal is brought by rail to the central distributing bin at Seattle, and from there delivered to the consumers' plants by motor trucks of special design. The railroad car for hauling the coal from the pulverising plant to the central bin

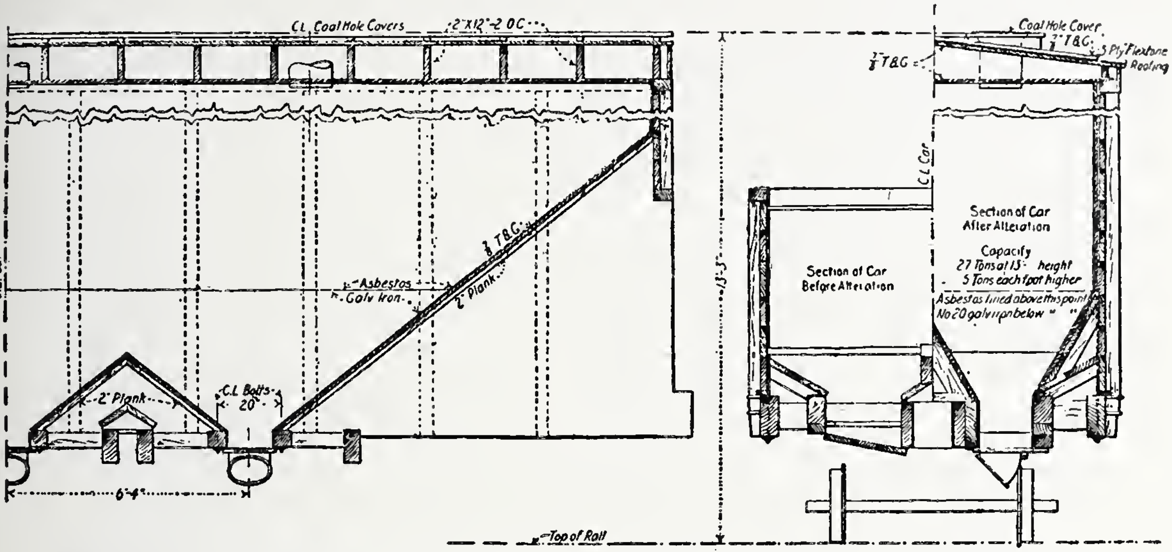


FIG. 212*a*.—Special Railway Truck used at Seattle by the Pacific Coast Coal Company for delivery of pulverised coal. (*The Colliery Guardian.*)

at Seattle is shown in cross section in Fig. 212*a*, both in its original form and as later remodelled. The body of the car is of wood, lined with asbestos board, except for the hopper bottom, which is lined with sheet iron. The car has a capacity of 30 tons when completely filled. The intake openings at the top of the car and the discharge openings at the bottom are made with special castings, and can be tightly closed. The density of the pulverised coal varies considerably with the degree of settling. An average figure is 40 lb. per cu. ft. This car, in its present form, is giving satisfactory service, and others, to be added as the traffic demands, will be of the same design, but of all-steel construction. A small all steel inter-departmental supply railroad truck is shown in Fig. 209.

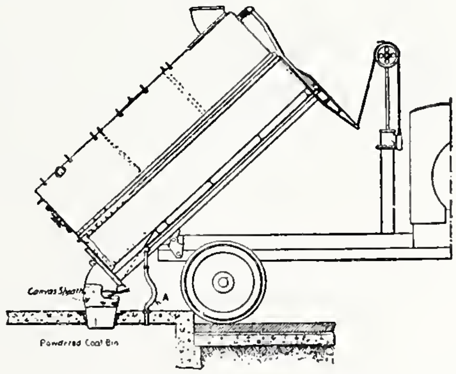


FIG. 212*b*.—Motor Road Truck used by the Pacific Coast Coal Company for delivery of pulverised fuel to small consumers, showing air relief connection.

The motor truck, Fig. 210, used in delivering the pulverised coal to the consumers' plants is of an original design, and was built in the Company's own shops. Fig. 212*b* is a sketch of the truck body in position for discharging into a bin or bunker. The small pipe A makes an air connection between the top of the bin and the top of the truck tank. This greatly facilitates dumping, and renders the operation entirely dustless, since the air displaced from the bin by the coal enters the emptying tank. In filling the truck, the tank body is tilted in the same

position as shown for discharging. The 45° elbow at the top of the tank then makes a tight connection with a spout from the bin. The intake and discharge openings of the truck are closed by tight-fitting ratchet gates.

The central distributing bin at Seattle has a capacity of 80 tons, and, on an average, 60 tons are held in reserve at this point. The bins at the consuming plants are all of the same type. They are built either of steel or concrete, and hold from 10 to 25 tons. These bins are usually kept full, and the coal is probably in storage here longer than at any other point in the system.

All the handling and conveying machinery in various operations is enclosed, and in every case is so designed as to prevent exposing the dry pulverised coal to the atmosphere. The storage bins are, as far as possible, made air-tight, in order to prevent circulation or the renewal of the enclosed air. It is worthy of note, even as a coincidence, that the only three occasions of serious heating of the powdered coal in bins occurred when the material had accidentally been wetted.

A new Central Supply Company at Terre Haute, Indiana, has recently started operations, and, from all accounts, is operating with success. There are other Public Supply Companies operated by a parent Company—The American Atomised Fuel Co., Shelbyville, Illinois—with Central Depôts at St. Louis, Michigan, and South Bend, Indiana.

Small Consumer's Burner Equipments.

The apparatus to be installed at the furnaces in which the fuel is to be burned must comprise a fuel hopper, a means of feeding the fuel at a regular rate, and a supply of air for combustion of the coal.

The present-day types of burner equipment, fitted with all necessary control devices, are the outcome of improvements to the crude types of coal burners originally used.

A heating plant using 1200 lb. of coal per day of 24 hours will burn in the heating season of 8 months in pulverised form approximately 144 tons. Prior to adopting pulverised coal firing, which is assumed to introduce an economy of 30 %, there would be burned $\frac{144}{70} = 206$ tons of coal under the old methods. The saving in fuel will be $206 - 144 = 62$ tons.

A complete unit to burn the above amount of coal will cost the purchaser about $600.

It is suggested that units should be built in several different sizes to suit the varying conditions of users; thus the small size might be designed for application to hot-water heaters, and arranged for burning between 1 and 5 lb. of coal per hour. The cost of this unit would be about $200 (coal containers used).

The next size, having say a capacity of from 5 to 25 lb. of coal per hour, would cost about $400 (coal containers used).

The next size, having a capacity of from 10 to 50 lb. coal per hour, would cost about $600 (coal containers used).

The largest size will perhaps have a capacity of from 25 to 125 lb. per hour, and will cost about $800 (exclusive of the cost of a fixed coal-bin).

Fig. 213.—Stroud Small Consumer's Equipment.

E. H. Stroud & Co.]

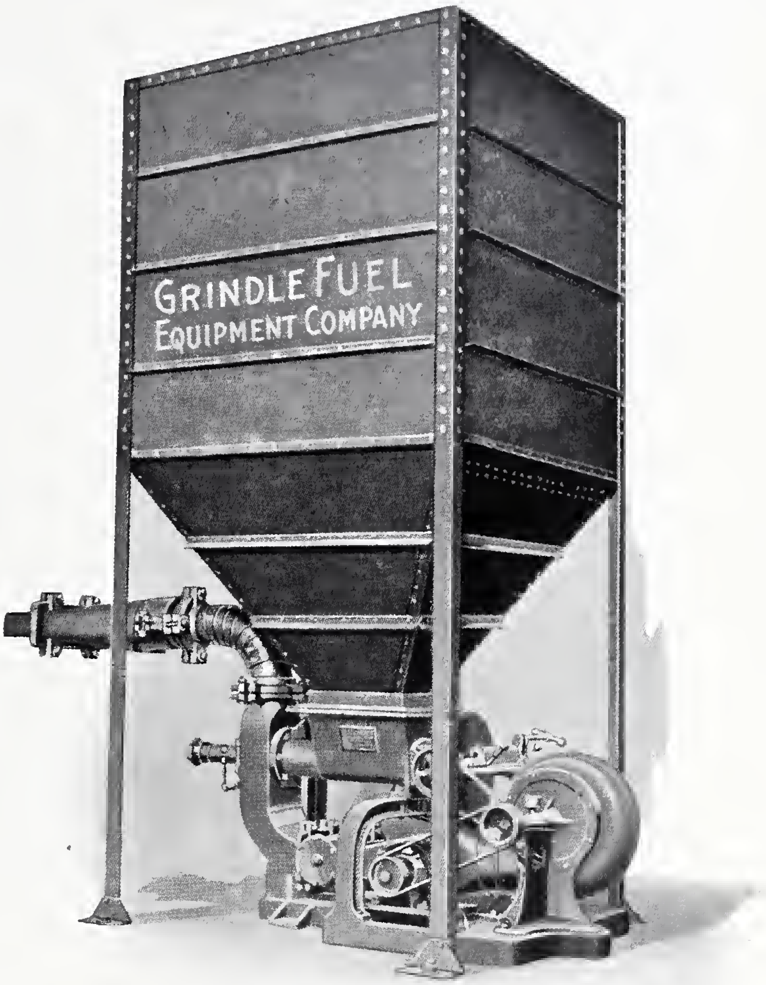


Fig. 214.—Grindle Small Consumer's Equipment with Fuel Storage Bunker.

Grindle Fuel Equipment Co.]

[*To face p.* 368.

It would not be practical to use containers for burner units requiring more than 50 lb. of fuel per hour. For units above that rating, coal would be supplied from a steel hopper coal-bin to which the coal would be conveyed from the motor delivery truck.

Kinyon Equipment.

Figs. 211 and 212 illustrate the Kinyon small consumers' units, the functions of which he describes as follows :—

The unit completely assembled has a 55-gallon steel barrel, which holds about 300 lb. of pulverised coal in position above the hopper, and connected thereto by an air-tight sleeve, so that there can be no escape of the coal dust while the contents of the barrel are being fed into the burner unit. This view also shows very clearly the present blower direct connected to a $\frac{1}{4}$ h.p. motor for supplying the entire amount of air required for the complete combustion of the fuel. The gear and crank by which the crane is operated for lifting the barrel of coal into position is clearly shown in this view.

There will be noticed directly under the trunnion in the end of the crane arm an opening in the sleeve connecting the barrel to the hopper, into which a wrench is inserted for opening the valve in the head of the barrel, after the barrel is in position, and also after the sleeve has been pushed down to make an air-tight connection.

The side elevation view of the unit shows the crane in reverse position. In this view will be noticed the gauge glass in the side of the hopper, by which the observer can see the level of the coal when the barrel is emptied and the coal in the hopper is getting lower. To the extreme left of this view, and projecting beyond the frame of the unit, is seen the burner, which is introduced into the fire door of the furnace or boiler, and through which the coal, supplied by the fan with air for its complete burning, is blown into the furnaee. The coal-feeding mechanism is contained in the casing at the bottom of the hopper, and immediately at the back of the burner.

Stroud Equipment.

A simple Stroud combination unit is that shown in Fig. 213, which consists of a standard blower arranged for mixing pulverised fuel, within the fan housing, with the air required for combustion. Upon the blower casing is mounted a fuel hopper, from which the fuel is withdrawn by a screw feeder operated by chain drive and a worm-wheel reduction gear fitted to the fan shaft. Arranged in this manner, the revolutions of the feeder screw are in proportion to the speed of rotation of the fan, so that, by regulation of the latter, a certain degree of correlation is obtainable between the quantity of air delivered and that of fuel fed into the fan casing.

Grindle Equipment.

Another type of self-contained air blower and fuel-feed unit is shown in Fig. 214. This is the Grindle small consumers' pulverised fuel-burner equipment. The method of driving the fan and fuel-control feed screw by means of one motor is clearly shown, and the reference remarks given explain the function of the various

parts of the apparatus. The delivery pipe is connected up with a special carburettor, and patent burner built into the wall of a furnace combustion chamber. A view of such a unit as installed for use with a metal-melting furnace is shown in Fig. 215.

The special features of the Grindle equipment lie in the design of fuel hopper and feed screw, the feed control and the carburettor. In order to prevent packing of the pulverised coal in the hopper, the feed screw is enclosed in a cast-iron hopper

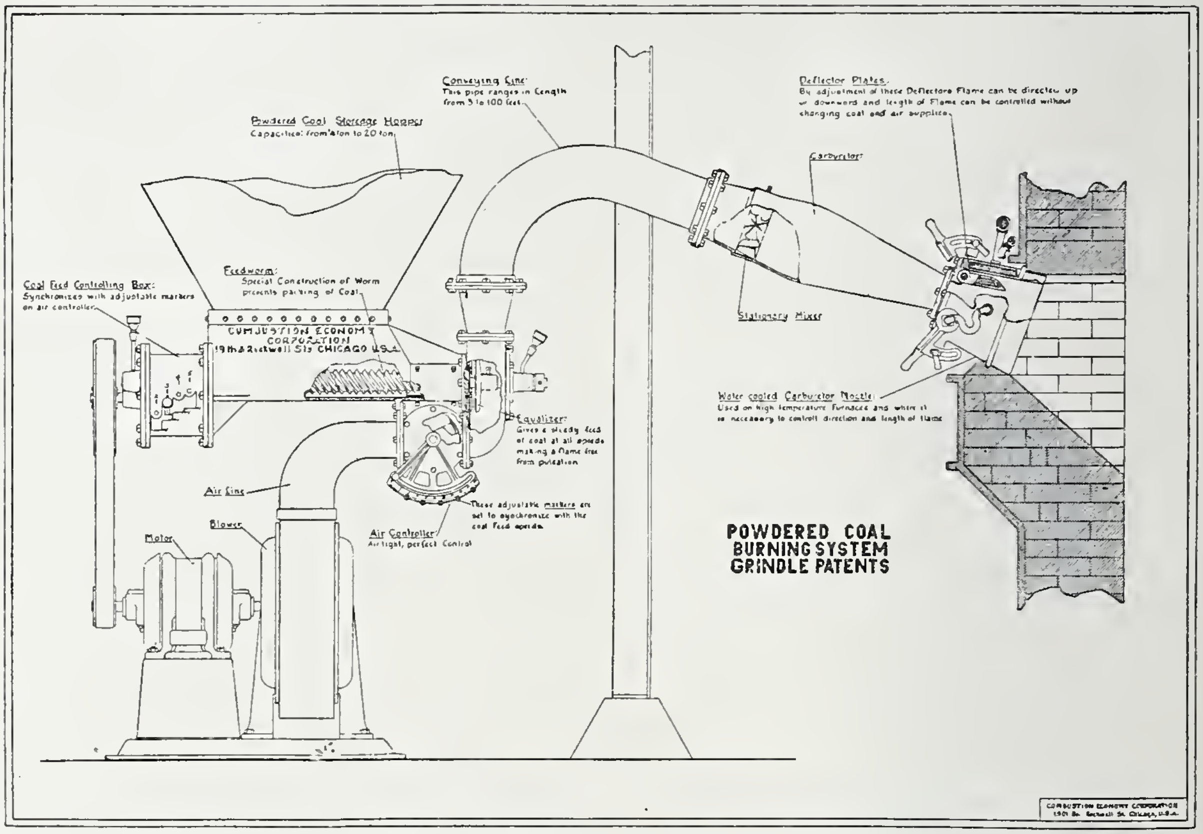


Fig. 215.—Grindle Small Consumer's Unit as applied to a Melting Furnace (*The Grindle Fuel Equipment Co.*)

bottom with a large top opening, and is fed throughout its whole length with fuel, a revolving disc at the discharge end breaking up any packing that may occur at that point.

Capacities of Grindle Small Consumers' Units.

Type.	Capacity per Minute.		Capacity per Hour.	
	Minimum.	Maximum.	Minimum.	Maximum.
U–00	1 oz.	4 oz.	$3\frac{3}{4}$ lb.	15 lb.
U–0	3 oz.	12 oz.	$11\frac{1}{4}$ lb.	45 lb.
U–1	8 oz.	2 lb.	30 lb.	120 lb.
U–2	1 lb.	3 lb.	60 lb.	180 lb.
U–3	2 lb.	6 lb.	120 lb.	360 lb.

Fuel mixed with air supplied by the blower can be conveyed up to 100 ft. and delivered through the carburettor to the burner. In passing over the fan blades of the mixer fitting, a swirling motion is imparted to the fuel and air, thereby intimately mixing the two, and producing a steady flame at the burner. The burner is fitted with special deflector plates, which can be adjusted to produce the type of flame required. By altering the angle of these plates a long or short flame can be produced.

The foregoing remarks refer, in particular, to the supply of fuel from a central depot to consumers whose requirements are smaller than would warrant the use of the self-contained pulveriser and burner units, or who, for other reasons, may prefer to take delivery of pulverised fuel and to burn this in furnaces using the simple types of burner equipments described.

Pruden Equipment.

The Pruden small consumers' unit is shown in Fig. 216. This is semi-automatic in its operation. One motor drives the feed screw for the fuel supply and also the fan for the air supply. By means of a synchronising mechanism, the air supply is automatically reduced or increased as the speed of the motor is altered to suit the rate at which fuel is to be burned.

Self-Contained Pulveriser Units.

The next type of machine to be considered is that in which the actual pulverising of the coal is carried out *in situ*.

Until recent years, it was the general opinion of pulverised coal experts that the then existing types of self-contained units were very imperfect machines, both as to their mechanical design, and also in regard to the production of powdered coal of the required fineness and uniformity.

The imperfections of machines become more apparent as the firing problem becomes more difficult, and in boiler firing, for instance, when combustion areas may be somewhat limited and the relatively cool surfaces of boiler plates and tubes are in the path of the flame, good results will not be obtained with any but the most efficient types of self-contained units. For these reasons, the use of this class of apparatus without every consideration being given to the design, both of machine and combustion chamber, may tend to obscure the advantages and economy to be obtained from the use of pulverised fuel when burned under approved conditions.

The outstanding attractions of the unit pulveriser are the small space that it occupies and the small capital outlay involved. It is on account of these advantages that such pulverisers serve a very useful purpose as a means of carrying out preliminary experiments, and of demonstrating, in a small way, many of the possible applications of pulverised fuel.

A brief description of some of the well-known types of machines is given in the following pages.

During recent years much progress has been made, and several new types of grinding machines of the disintegrator and revolving disc types can now be obtained which will give excellent results. Self-contained pulveriser units can now be obtained to operate either with previously dried raw coal of sizes up to 2 in. cube,

or with coal containing 15 to 20 % of moisture, and in each case capable of delivering a more or less uniform and finely pulverised fuel to the furnaces. In the case of a high moisture fuel, heated air is passed through the machine used in such instances, in order to evaporate the water from the coal and to leave the actual pulverised product relatively "dry." In this manner a 20 % moisture coal can be pulverised and delivered to the burner with not more than 3 % or so of free moisture. The water thus evaporated is usually passed into the combustion chamber with the fuel. This does not prevent good firing conditions and satisfactory results from being realised, where the presence of moisture in the shape of superheated steam is not detrimental to the particular operation.

Small self-contained pulveriser units can be installed with every confidence of success when only a limited quantity of pulverised fuel is required, or when initial tests on a small scale are to be carried out. The heavy cost of rotary dryers, elevators, storage bins, crushers and other items, with the requisite motors and building to take this composite equipment, being eliminated, the installation of self-contained units is a less expensive means of obtaining results which, in many instances, are sufficiently satisfactory.

Rotary disc disintegrators of accepted design are quite efficient machines, and produce uniformly fine pulverised fuel. This type of disintegrator is free from internal journals and bearings, which would be subject to the abrasive action of pulverised coal. Such machines can also be run light or empty, for there are no mechanical rubbing or rolling surfaces.

The beater type of self-contained unit, as will be seen from the illustrations, is sometimes fitted with intermediate journals and bearings in the pulverising zone, so that, as regards the scoring of bearings, this type is not so free from wear as the disc or disintegrator machines.

Furthermore, with the usual beater type of machine, the degree of fineness and uniformity of the finished product, requisite for efficient working, is not always obtainable under more exacting conditions. The cost of repairs, also, may be high, owing to the wear and tear of beater and other machine parts of unsuitable design.

Under certain conditions, where coal-dust firing offers no difficulty, and where ash and slag deposits are not serious considerations, such as in cement kilns, almost any self-contained unit will operate with success.

The Atritor Unit.

The "Atritor" unit, Figs. 216*a*, 217, 218 is the invention of C. E. Blyth, at the date of this book Managing Director of Charles Nelson & Co., the well-known manufacturers of cement, and the author has witnessed the successful results obtained with "Atritor" machines used for drying and grinding 17 % moisture slack coal direct to 80 %, 200-mesh, standard pulverised product, containing only about 3 % of moisture. The machines of the Stockton Cement Works are, naturally, used for the direct firing of rotary kilns.

The illustrations here reproduced, and the following brief description, are taken from *The Engineer*, August 5th, 1921. The machine consists of a cast-iron casing, in which revolves at high speed a steel disc, which practically has the effect of

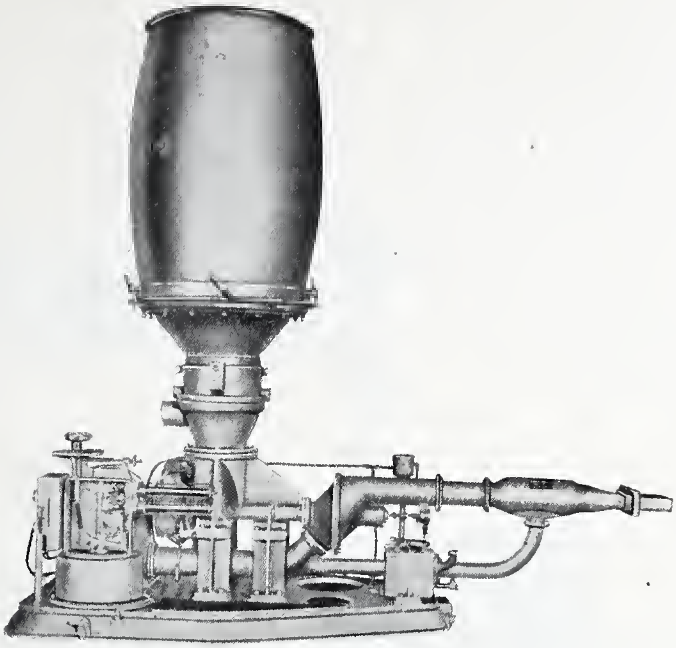


Fig. 216.—Pruden Small Consumer's Equipment.

Powdered Coal Engineering & Equipment Co.]

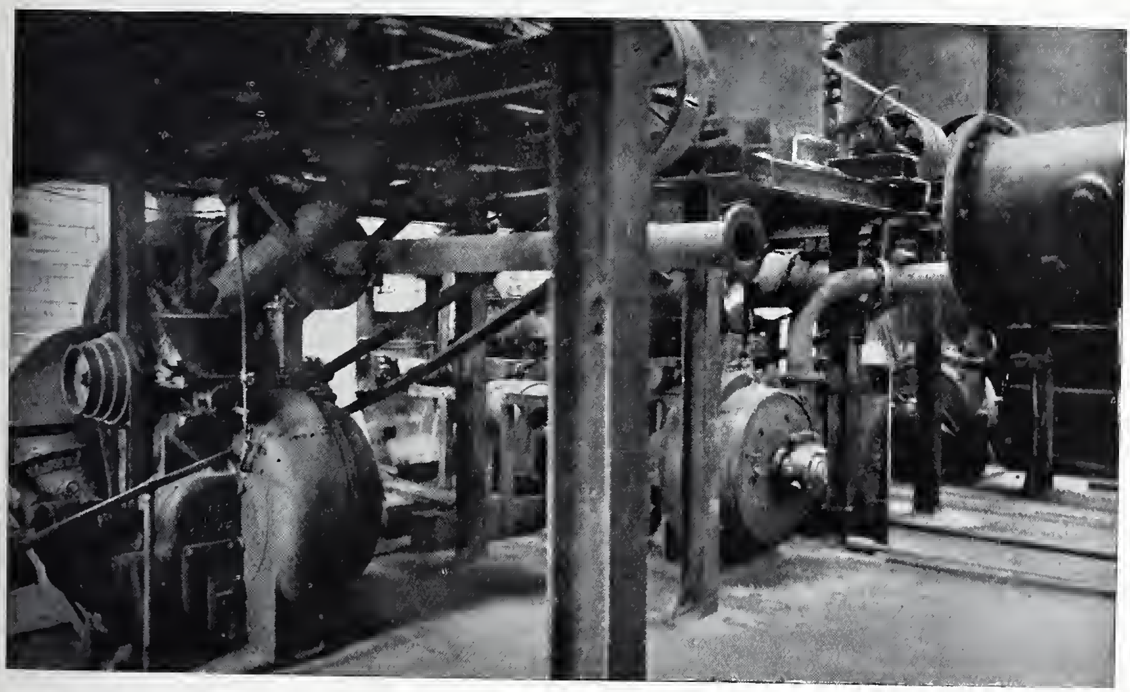


Fig. 216*a*.—Installation of Three Atritor Self-contained Units at Cement Works.

Alfred Herbert, Ltd.]

[*To face p.* 372.

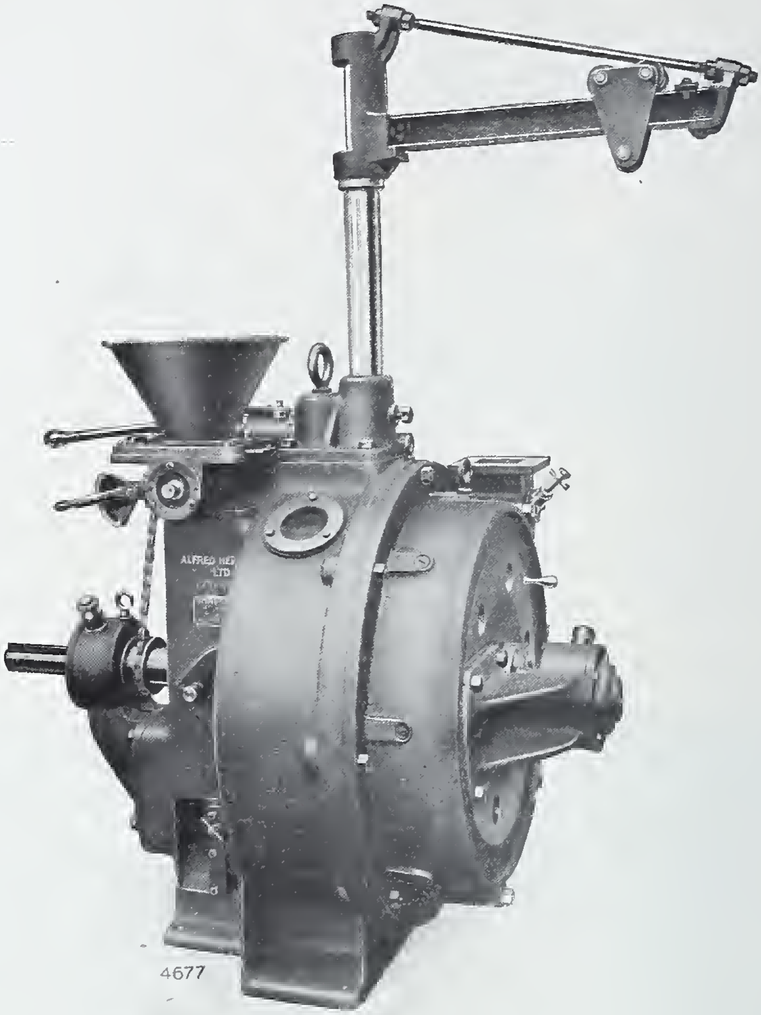


Fig. 217.—General View of Atritor Pulverised Unit.

Alfred Herbert, Ltd.]

dividing the casing into two parts. The disc is fixed on the shaft, which is carried in the bearings seen in the illustrations. The disc has mounted on both sides of it four concentric rings of projecting studs of especially hard steel, some of which are square and some round. The studs do not project so far from the disc as to touch the sides of the casing. Screwed into both internal faces of the casing are similar rings of studs, which are so arranged that when the disc is in position the rings of studs on the latter intermesh with, and revolve between, the rings of studs on the casing, without, however, touching them. Mounted on the disc at its periphery, on the coal inlet side, is a fan of the Sirocco type, which has the effect of drawing air into the casing.

The coal is supplied to the machine by way of the hopper at the top, which is provided with a worm feeding gear, driven by belt from the main shaft by the cone pulleys, so that four variations of feed are possible. The raw coal, which should be in pieces of not more than 1 in. cube, but may be anything smaller than that, is delivered into the hopper. The suction fan draws in air through the port shown at the base of the machine, and for fine adjustment of the air required for efficient combustion a series of " hit and miss " air holes is arranged in the circular side plate, capable of being moved by hand.

In order to effect the drying of the coal, a supply of heated air can be introduced into the pulverising chamber. In the case of a cement plant, the air may usefully be obtained from the clinker cooler, and at the cement works in which the " Atritor " has been put through the experimental stages the temperature of the incoming air was usually about 550° F. The revolution of the disc has the effect of throwing the incoming coal outwards away from the shaft, and the path of the fuel is fanwise and between the fixed rings of studs on the casing and the revolving rings of studs on the disc. Apparently, up to the time when the coal has reached the interior periphery of the casing, but little, if any, fine grinding has taken place, but, on the other hand, the incoming hot air has taken up a large proportion of the moisture in the fuel.

Under the influence of the current of air set up by the fan, and assisted by a second similar fan fixed on and revolving with the shaft inside the casing on the side of the disc remote from the first fan, the coal continues its progress through the machine, and as it does so travels inwards, away from the inside periphery of the case, between the studs on the side of the disc pointing away from the inlet and the studs fixed on the casing facing it. The path taken by the coal through the machine is, therefore, U-shaped, first away from the shaft and then towards it again, so that, for the latter half, its direction is against centrifugal force. The introduction of a circular grid or screen prevents the passage of unpulverised lumps of coal, and throws them back between the fixed and revolving studs, where they are broken up. Practically all the fine grinding takes place as the coal travels from the interior periphery of the casing towards this inverted fan.

There appears to be no difficulty whatever in obtaining any desired amount of fineness in the grinding, or in producing dry powdered coal, even though the initial moisture content be as much as 20 %.

The coal and the air for combustion travel through the machine together, and are led directly from the machine into the tube leading to the burner.

The inventor is of opinion that the vaporised moisture in the mixture causes the formation of water gas in the kiln, the combustion of which takes place in the furnace.

In contrast with the existing methods of drying and grinding coal for the purpose of firing cement kilns, the inventor claims :—

(*a*) That the "Atritor" takes the place of the elaborate, expensive and dirty plant hitherto employed for the purpose;

(*b*) That it is continuous in action, and dispenses with the necessity for storage bins for the pulverised coal;

(*c*) That the drying and pulverising go on together, the product being burnt immediately without being given opportunity to absorb moisture after pulverisation;

(*d*) That all the volatile constituents of the fuel pass into the kiln and are burned;

(*e*) That the raw coal is fed into a hopper at one end and burnt in a finely divided state like gas at the other end;

(*f*) That it is driven by a single motor, and requires no auxiliary fans, elevators, or conveyors, other than what is necessary to feed the raw coal into the hopper;

(*g*) That when used with a rotary cement kiln the machine produces a better quality and a higher output of clinker per ton of coal than was the case with the accepted standard arrangement of dryer and pulveriser equipment previously used;

(*h*) That a rotary kiln fired by an "Atritor" is ready for use forty minutes after lighting up;

(*i*) That the power required by it is less than half, and the labour only about one-fourth that needed for the usual processes of pulverising and drying;

(*j*) That with it the production of dirt and dust in the proximity of the pulverising machinery is entirely avoided;

(*k*) That the cost of its maintenance is very small, and not in any way comparable with the charges for repairs and maintenance of the usual "complete" plants;

(*l*) That it is a cheap and simple matter to have a spare "Atritor."

When coal is both dried and pulverised in a unit such as the "Atritor," it is found that there is little loss of volatile constituents of coal. This is certainly an important point when fuels containing high percentages of volatile material are present. It has been found that in ordinary rotary dryers, more especially with those of the direct fired type, a 10 %, 15 % or even 20 % reduction in the B.Th.U. value of the fuel may result from the loss of volatile material during the operation of drying the coal.

With a machine of the "Atritor" or similar type, unless the fuel is delivered to a bag filter or cyclone separator, both the moisture evaporated and the volatile products are fed with the pulverised coal into the furnace. Fuel separated out in this manner may be at too high a temperature for lengthy storage. The usual means must then be taken to guard against spontaneous combustion, if storage of the fuel is required.

It has been stated that coal containing 20 % moisture can be reduced to 2 % or 3 % moisture in this manner when preheated air or hot waste gases are passed through the pulveriser. With air at normal atmospheric temperature, coal con-

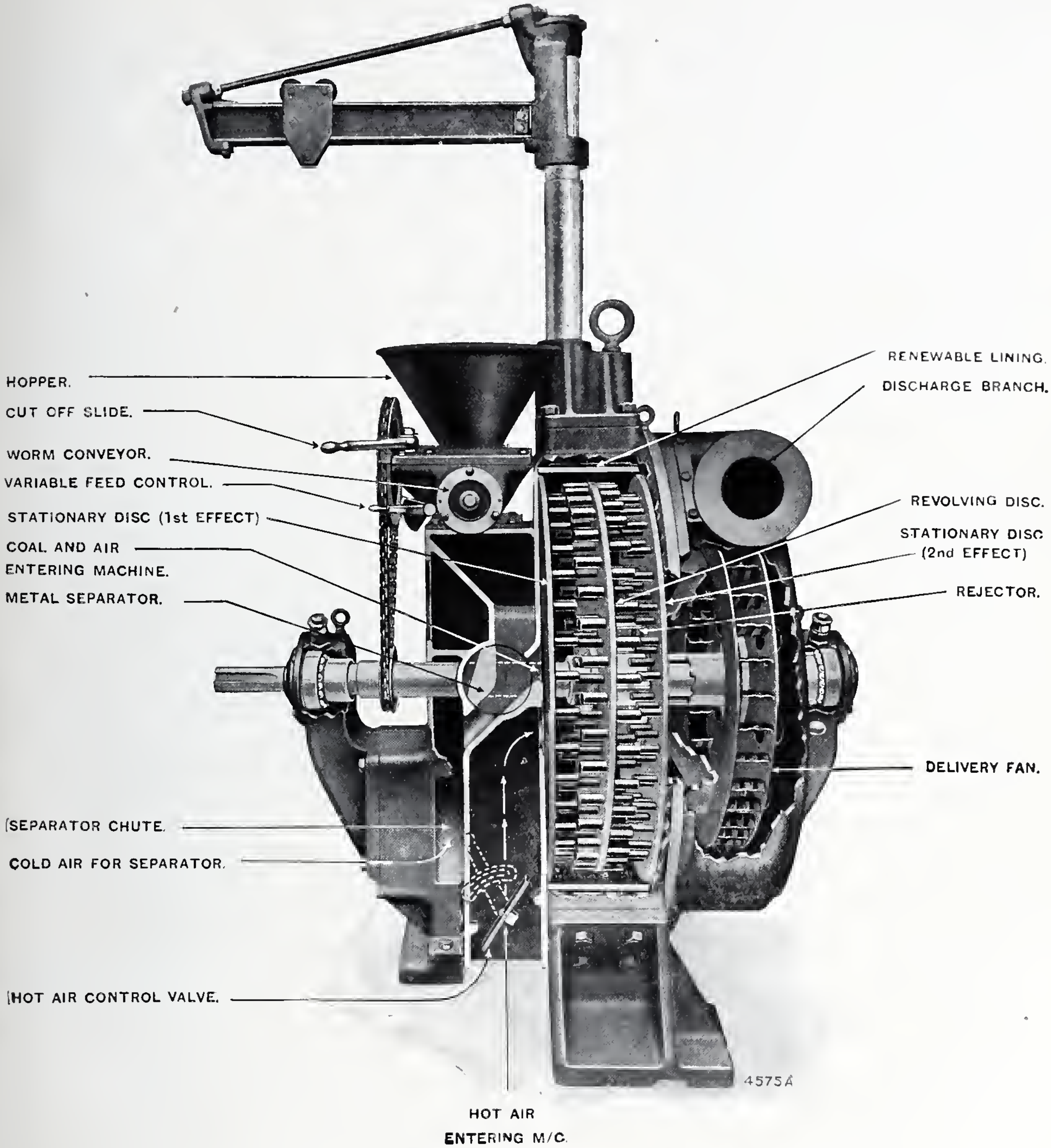


FIG. 218.—VIEW SHOWING GRINDING ELEMENTS AND EXHAUST FAN WHEEL, ATRITOR SELF-CONTAINED UNIT.

Alfred Herbert, Ltd.]

[*To face p.* 374.

taining 10 % of moisture can be readily handled and the moisture content reduced to 2 %.

The power absorbed for the latter duty is approximately 1 B.h.p. per 100 lb. of coal pulverised, or about 22 h.p. per ton, the degree of fineness of product showing 4 % residue on a 180-mesh screen.

By the addition of a small quantity of liquid fuel—paraffin, for example—to a low-grade coal, the inventor of this machine has found that it is quite a simple matter to pulverise and satisfactorily burn coal containing 27 % of moisture and 54 % of ash. The amount of paraffin that need be used is quite insignificant, being only 1 lb. per ton of coal, and its addition to this extent, it is said, has a very distinct subsequent value when burning high ash coal in pulverised form. This discovery by the inventor of the "Atritor" machine confirms the results of a somewhat similar nature obtained by Colonel Bonner when making experiments in the preparation of pulverised coal for firing locomotive boilers in India.

The "Aero" Unit.

The "Aero" pulveriser is one which has been very widely adopted. It was undoubtedly the forerunner of the many newer types now available. It is a small compact pulveriser unit, and has been extensively used in cases where a comprehensive mill plant would have been out of place, and for pulverising fuel to the degree of fineness required for ordinary purposes it has proved very satisfactory.

The pulveriser is shown open in Fig. 219. It is of the beater type, and no dryer is used, as a rule. Coal is fed into the reciprocal feed chamber, coal and air entering together; the pulverisation and air mixing take place during the one operation. Rotary fan blades, attached to the main shaft at the discharge end, induce a current of air through the mill and remove the particles of coal.

Although of a somewhat crude design when compared with later types of machines, many hundreds have been installed in cases where small quantities of pulverised coal have been required. Self-contained units of more recent types are in many respects to be preferred to the original "Aero" mill.

J. S. Atkinson in England has greatly improved upon the original construction of the "Aero" unit, and in France and neighbouring countries La Combustion Rationnelle has supplied hundreds of these "turbopulvérisateurs" during the past three years.

As an indication of the space occupied by "Aero" self-contained units and the power of motors for operating machines of various capacities, the following details are given for standard machines.

Size.	Weight in Lb.	Height (in inches).	Floor Space (in inches).	Normal Load Soft Coal (lb. per hour).	R.P.M.	Normal Power Consumption.*	Horse-Power of Motor Recommended.
A	2,250	$28\frac{3}{4}$	$61\frac{3}{4} \times 27\frac{3}{4}$	600	2,050	10	15
B	4,000	45	$77\frac{1}{2} \times 29$	1,000	1,750	14	30
D	5,400	$46\frac{3}{4}$	$85\frac{3}{4} \times 29$	2,000	1,550	30	45
E	5,900	50	89×33	3,000	1,450	40	60
G	12,000	59	116×40	5,000	1,450	65	100

* The load may be increased 25% or decreased 50% without material loss of economy.

An illustration showing a boiler fired with pulverised coal supplied from a Turbo pulveriser, an improved "Aero" type machine, installed by the Powdered Fuel Plant Co. at an English colliery, is shown in Fig. 220. Extracts from a description of this installation (published in *The Iron and Coal Trades Review*, August 4, 1922) are given below :—

The installation has been made at the Philadelphia Power Station of the Lambton and Hetton Co., and has been thoroughly tried out over a period of twelve months, its duty being the firing of a Babcock and Wilcox boiler of 20,000 lb. evaporative capacity. The installation is of particular interest, because it furnishes graphic testimony of the possibilities of turning to profitable account, in the form of powdered fuel, an otherwise semi-waste product.

The material currently used to feed the pulveriser at the Philadelphia Power Station is "Durham Splints," of which the following is an approximate analysis : moisture, 0·93 %; volatile matter, 24·67 %; fixed carbon, 41·24 %; ash, 33·16 %; calorific value, 9550 B.Th.U. Owing to its nature, this material does not give satisfactory results on the usual forms of mechanical stokers or fixed grates, as, when this fuel is burnt on a grate, disintegration does not take place, as it does with most other fuels, and it is quite usual for a lump to leave the discharging end of the mechanical grate in the same shape as when originally charged.

The turbo-pulveriser, which, it will be seen, is installed well above floor level, so as to be out of the way, has a normal capacity of 3000 lb. of coal per hour, and is driven by a 50 h.p. motor through a set of 1-in. laminated gears, so as to give the pulveriser a speed of 1450 r.p.m. On ordinary ratings, the h.p. developed is in the neighbourhood of 30; the larger motor is, however, advisable, since, if the coal is delivered in a wet state, the power required for pulverisation increases.

On test, an overall efficiency of 74·1 % was obtained with the boiler and superheater, and, if to this is added the extra efficiency obtained by the economiser, the overall efficiency will be more than 80 %.

Combustion Test on Boiler-Fired with Turbo Pulveriser at Colliery Power-House.

Time.	CO_2. %	O_2. %	CO. %	Draft blr. front In.	Flue gas temp. °F.	Superheat steam temp. °F.	Motor ammeter.
11·25	16·8	0·6	—	0·05	490	—	45
11·40	16·0	2·2	—	0·05	500	—	45
12·0 (noon)	15·2	2·5	—	0·05	487	—	45
		At 12.20 p.m. combustion was arranged to be incomplete					
12·30	16·4	1·8	0·5	0·04	446	—	44
12·55	16·5	1·5	0·3	0·04	430	474	44
			Normal conditions resumed.				
2·30	15·9	2·0	—	0·06	440	476	42
At 2.45 p.m. an attempt was made to raise superheat by increasing speed of gases through boiler. Boiler damper was raised to further 1 in.							
2·50	12·5	6·9	—	0·02	442	484	40
		At 3 p.m. damper raised further 1 in.					
3·10	10·9	—	—	0·4	435	486	40
		Normal conditions of complete combustion resumed.					
3.45	17·0	1·5	—	0·07	440	478	43
4·15	14·7	4·3	—	0·04	430	482	42

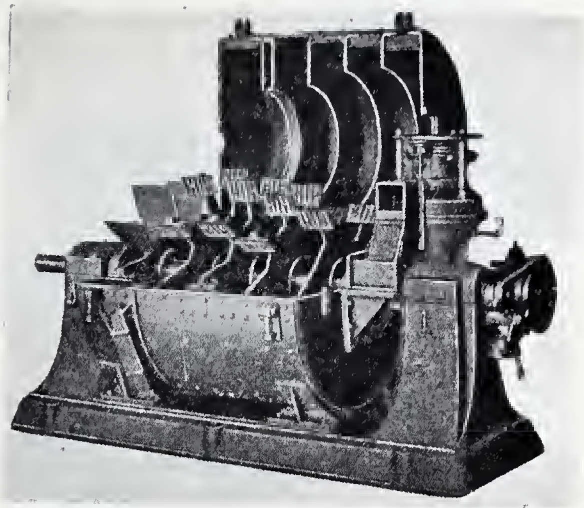


FIG. 219.—THE AERO SELF-CONTAINED PULVERISER UNIT (OPEN).

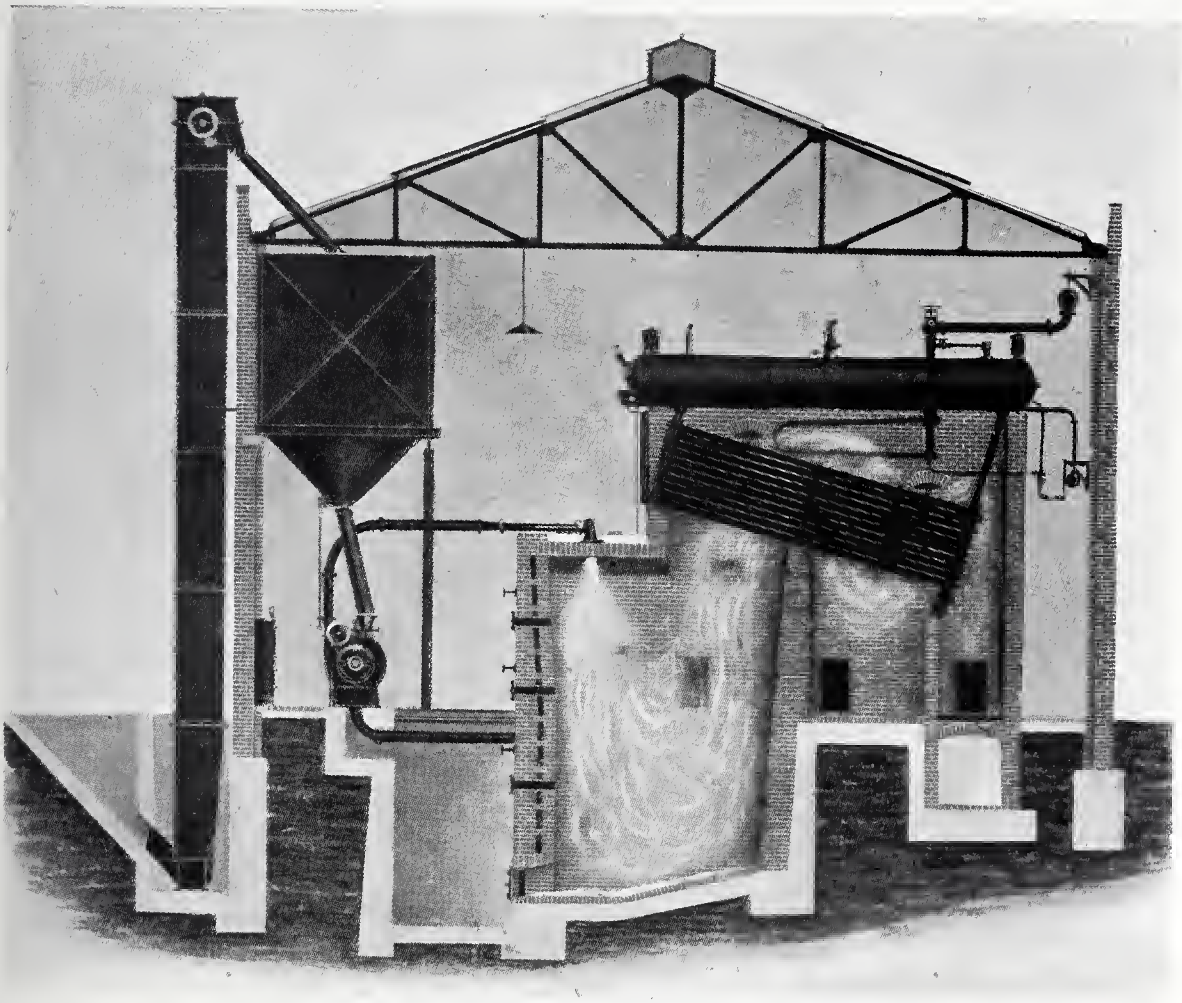


FIG. 220.—ATRITOR PULVERISER UNIT AND WATER-TUBE BOILER.

Alfred Herbert, Ltd.]

[*To face p.* 376.

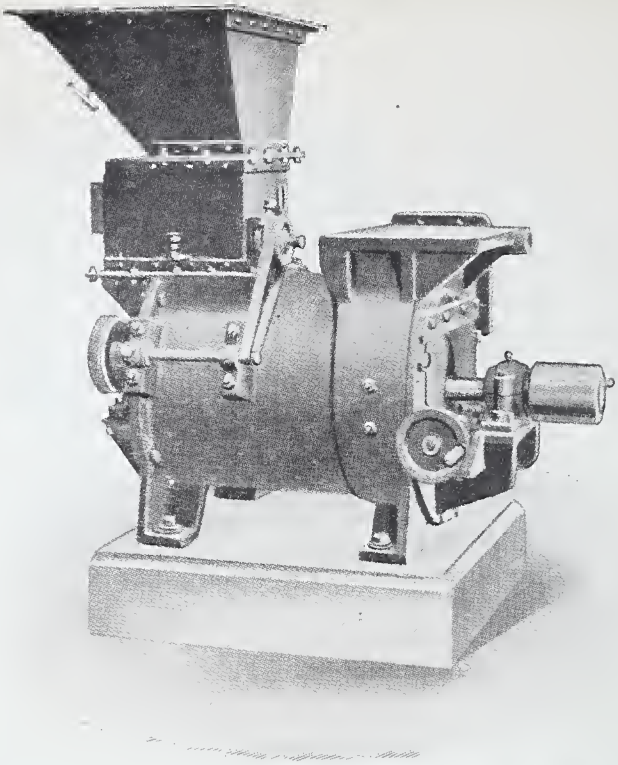


Fig. 221.—Simon-Carves Self-contained Pulveriser Unit.

Simon-Carves, Ltd.]

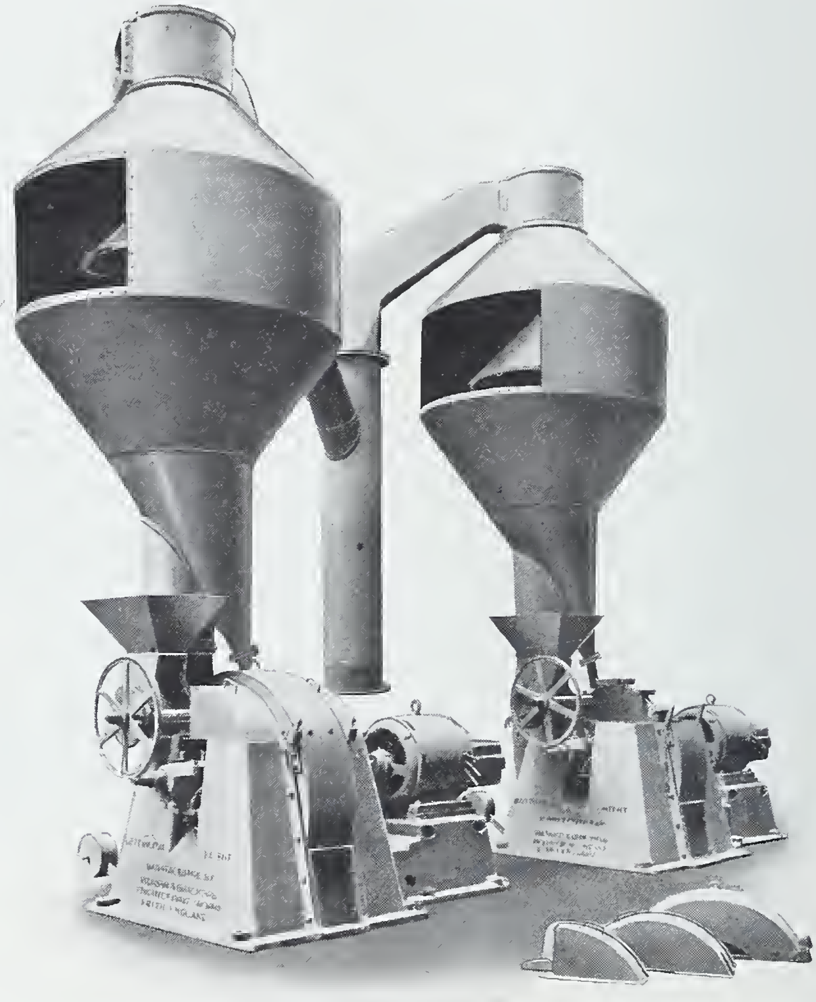


Fig. 222.—Bettington Self-contained Pulveriser Units and Cyclone Separators.

Fraser & Chalmers, Ltd.] [*The General Electric Co., Ltd.*

Simon-Carves Unit.

Another such type of unit pulveriser is shown in Fig. 221, the Simon-Carves machine, designed to operate by direct belt drive from a motor fitted on the platform or bracket shown. With this unit, coal containing up to 5 % of moisture can be pulverised. The powdered fuel is subsequently mixed with air supplied by a separate fan for conveying the fuel to the furnace burner.

The capacities of, and power required for driving, the various sizes of these units are approximately :—

Size.	Output lb. per hour.	Motor Rating h.p.	Power absorbed on bituminous coal. Average h.p.	R.P.M.
No. 1	280	7	5	3,000
No. 2	770	12	9–10	2,500
No. 3	1320	20	14–16	1,800
No. 4	2650	35	26–30	1,500

The " Bettington " Unit.

The Bettington pulveriser units are shown in Figs. 222, 223, 224. The Bettington unit is of the impact type and of very simple construction. The rotor consists of two mild steel-plate discs fixed about $1\frac{1}{2}$ in. apart on the shaft, and a number of T-shaped swinging beaters are secured by pins between these plates. Fan blades are formed on the side of these discs.

The casing is fitted with a number of impact bars arranged around the inner periphery in such a position as just to clear the ends of the swinging beaters. The pulverised material is passed through a screen at the lower side of the casing, and is blown into a small separator from which the larger particles are returned to the pulverising chamber.

The mixture of air and pulverised fuel of the correct fineness is blown direct into the combustion chamber of the boiler through a plain coned pipe.

When used in conjunction with a boiler or furnace, it is preferable that the air to the pulveriser should first be passed through a heater arranged at the base of the boiler stack or furnace outlet, the air supply thus entering the pulveriser at a temperature of 350° to 400° F. The introduction of a hot air supply appears effectively to convert the moisture in the coal into dry steam.

Coal containing from 15 to 20 % of moisture can be fed into the pulveriser, which will deliver a product of such fineness that 91 % will pass through a 200-mesh sieve. This is an astonishing result under the conditions. Such a performance should meet most requirements for firing even ordinary types of water-tube boilers, without recourse to the costly and cumbersome rotary dryer plant for the raw coal.

The relative silence under which the Bettington pulveriser runs is one of the special points in its favour.

For operating the 15,000 lb. boiler referred to, the pulveriser unit absorbs from 32 to 35 h.p. hrs. per ton of coal dried, pulverised and delivered to the furnace with all the air necessary for combustion. Upwards of 90 % of this power is absorbed by the air fan and bearing friction.

The parts of the pulveriser subjected to heavy wear, such as the beaters and beater bars, are made of manganese steel, and last from three to four months of continuous work. The Bettington Unit as applied to a standard water tube boiler is shown in Fig. 225*a*.

The "Seymour" Unit.

The Seymour self-contained pulveriser unit, Fig. 225, as supplied by the Erie City Iron Works, U.S.A., consists of a cylindrical housing containing a rotor mounted on a shaft, the rotor being composed of pulverising elements and a fan.

Coal of a size that will pass through a $1\frac{1}{2}$-in. ring is fed to the pulveriser, from which the fan withdraws the pulverised fuel mixed with sufficient air both to propel the coal dust through the pulveriser, and at the same time to effect combustion in the furnace. The air can be accurately regulated for both purposes, so that in the issuing mixture each particle of coal is surrounded by its proper proportion of air and it becomes possible to reduce excess of air to from 5 or 10 %, thus maintaining, it is claimed, from 16 to 17 % of CO_2 in the products of combustion.

The makers state that the power required to operate the different members of the equipment is approximately as follows, per ton of 2000 lb. per hour :—

Pulveriser	17 kw.
Magnetic separator	$1\frac{1}{2}$ kw.
Coal crusher	$\frac{1}{2}$ kw.
Elevating coal to a bunker . . .	$\frac{1}{2}$ kw.
Total	$19\frac{1}{2}$ kw.

Assuming 2 lb. of coal per kw. hour, which is a suitable allowance, the power cost in percentage of the coal burned would be :—$(19{\cdot}5 \times 2)/2000 = 0{\cdot}0195$, or 1·95 % of the coal pulverised.

Dimensions and Capacities of Seymour Pulveriser.

Size.	No. 1.	No. 2.	No. 3.	No. 4½.	No. 6.
Capacity (lb. per hour) . . .	1000	2000	3000	4500	6000
Max. Brake h.p. of Motor . . .	20	30	40	60	80
R.P.M.	1800	1200	900	900	720
Length by width .	3′ 9″ × 7′ 2″	4′ 0″ × 7′ 6″	4′ 6″ × 9′ 4″	4′ 9″ × 10′ 0″	5′ 0″ × 10′ 0″
Height	4′ 6″	4′ 9″	6′ 0″	6′ 8″	7′ 0″
Weight of Pulveriser	3600 lb.	5500 lb.	8000 lb.	11,500 lb.	15,000 lb.
Bedplate and motor, approximately .	5200 ,,	7500 ,,	11,000 lb.	16,000 ,,	20,000 ,,
Feed inlet dia. .	8″	8″	8″	8″	8″
Discharge dia. . .	12″	16″	18″	24″	28″

That good results are obtainable with the "Seymour" equipment for firing water-tube boilers with pulverised coal is shown by the data and results of the following evaporative test :—

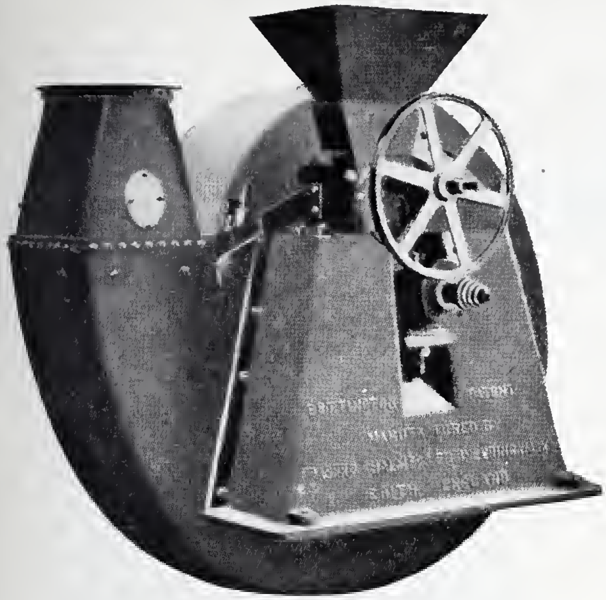


Fig. 223.—Bettington Self-contained Pulveriser Unit (closed).

Fraser & Chalmers, Ltd.]

[*The General Electric Co., Ltd.*

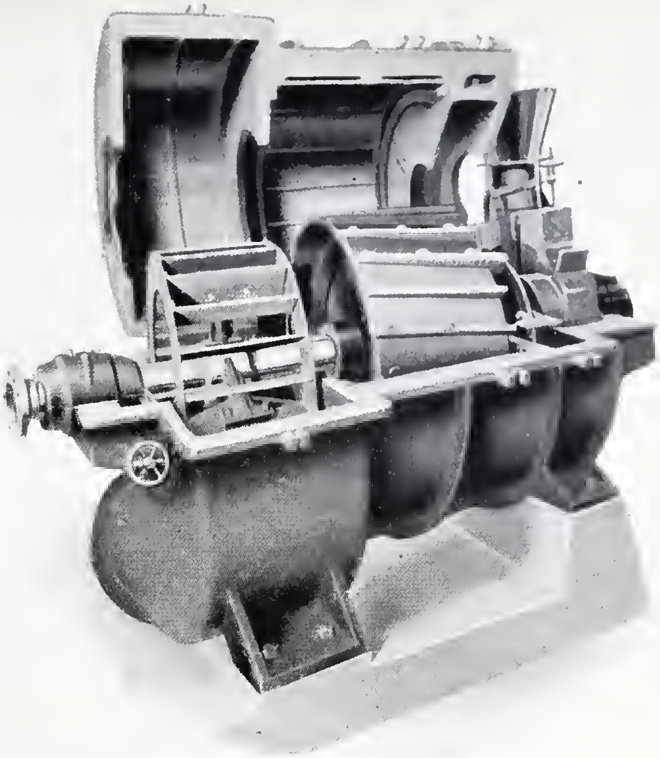


Fig. 225.—Seymour Self-contained Pulveriser Unit.

[*Erie City Malleable Works.*

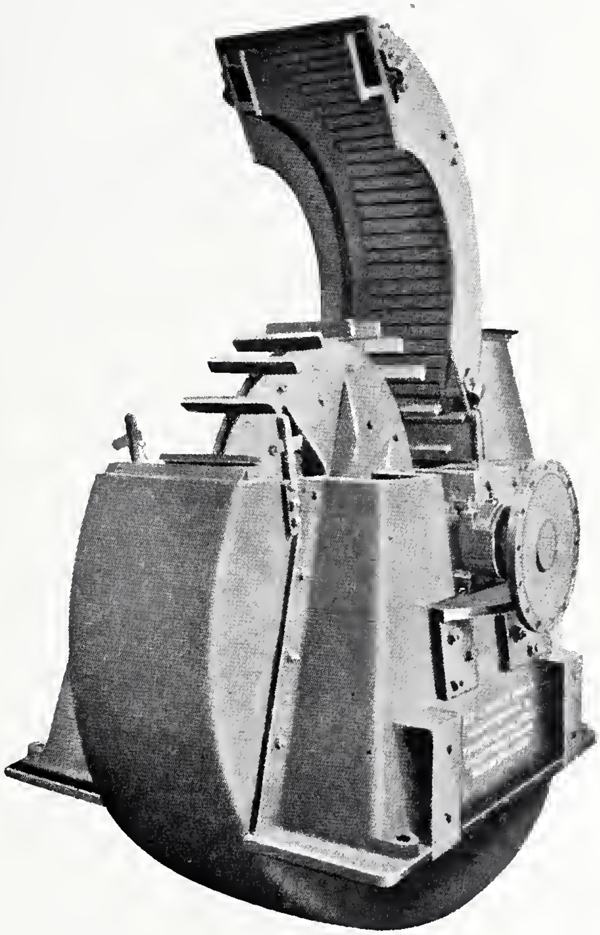


Fig. 224.—Bettington Self-contained Pulveriser Unit (open).

Fraser & Chalmers, Ltd.]

[*The General Electric Co., Ltd.*

[*To face p.* 378.

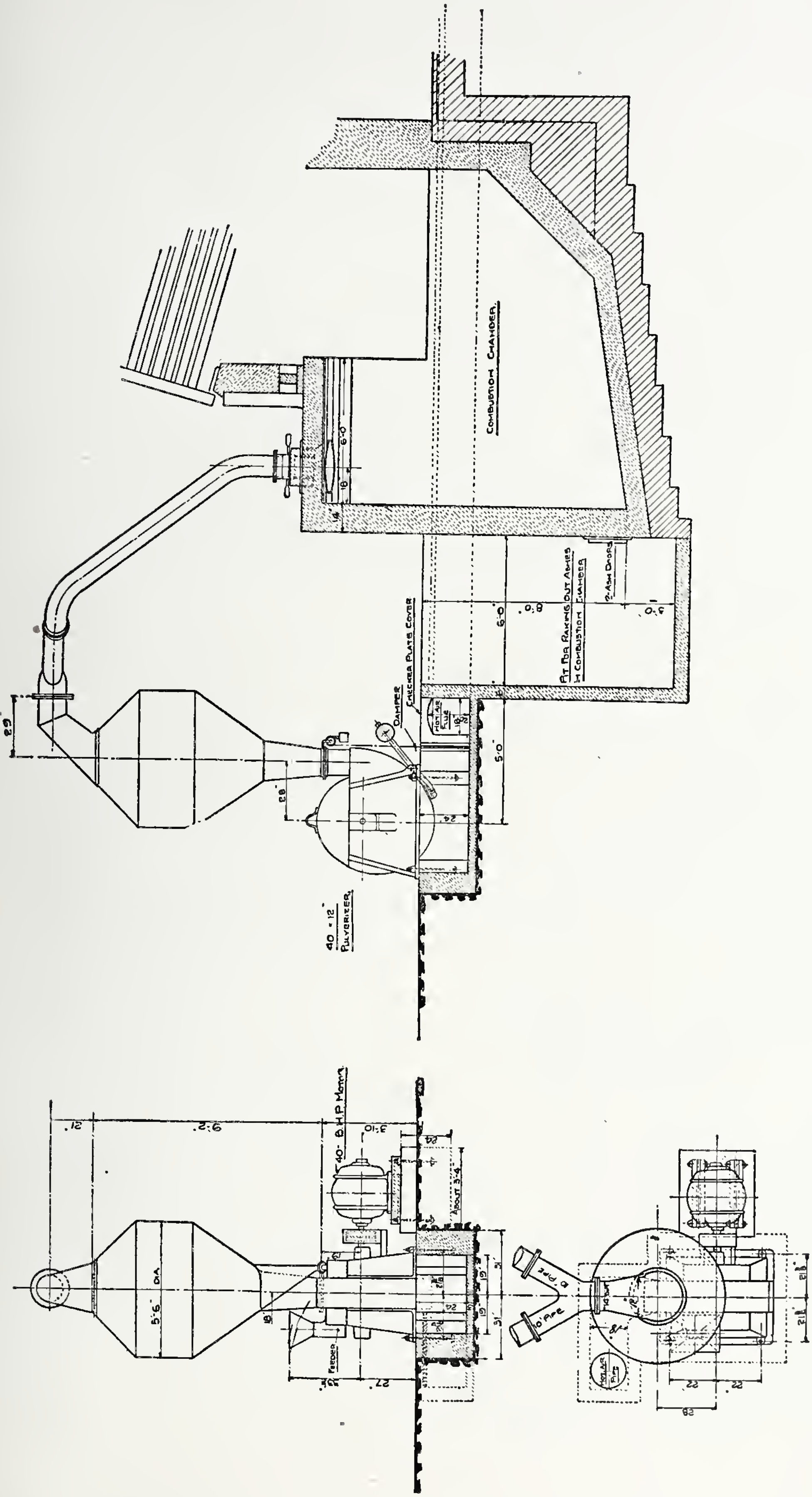


FIG. 225*a*.—Bettington Pulveriser Unit as applied to Standard Water Tube Boiler. (*Fraser & Chalmers, Ltd.*)

1. Test of No. 11 Horizontal Water Tube Boiler located at East Power House, Erie City Iron Works, to determine efficiency. Conducted by W. C. Heckeroth.

2.	Kind of furnace	Pulverised coal
3.	Grate surface, sq. ft.	none
4.	Water-heating surface, sq. ft.	4022
5.	Superheating surface, sq. ft.	none
6.	Date	4.14.21
7.	Duration (hours)	8
8.	Kind and size of coal	Pittsburg bituminous slack
9.	Steam pressure, by gauge, lb.	151·3
10.	Temperature of feed water entering boiler (deg.)	50
11.	Temperature of escaping gases leaving boiler (deg).	479
12.	Force of draft between damper and boiler—at outlet, (lb.)	0·13
	,, in furnace (lb.)	0·038
13.	Percentgage of moisture in steam	1·85
	Total quantities :	
14.	Weight of coal as fired * (lb.)	12,050
15.	Percentage of moisture in coal	8·9
16.	Total weight of dry coal consumed (lb.)	10,978
17.	Total ash (lb.) from chemist's analysis	2443
18.	Percentage of ash in dry coal from chemist's analysis	22·25
19.	Total weight of water fed to boiler † (lb.)	84,284
20.	Total water evaporated, corrected for moisture in steam (lb.)	82,725
21.	Total equivalent evaporation from and at 212° (lb.)	100,636
22.	Factor of evaporation	1·192
23.	Dry coal consumed per hour (lb.)	1,370·7
24.	Equivalent evaporation per hour from and at 212° (lb.)	12,542
26.	Equivalent evaporation per hour from and at 212°, sq. ft. of water heating surface (lb.)	3,118
27.	Water evaporated per hour corrected for quality of steam (lb.)	10,341
	Economy results :	
28.	Water fed per lb. of coal fired (item 9 ÷ item 14) (lb.)	6,994
29.	Water evaporated per lb. of dry coal (item 20 ÷ item 16) (lb.	7·54
30.	Equivalent evaporation from and at 212° per lb. of dry coal (item 21 ÷ item 16) (lb.)	9·148
31.	Equivalent evaporation from and at 212° per lb. of combustible (lb.) (item 12 ÷ item 16 — item 17)	11·75
	Efficiency :	
32.	Calorific value of 1 lb. of dry coal, B.Th.U.	10,938
33.	Calorific value of 1 lb. of combustible, B.Th.U.	14,068
34.	Efficiency of boiler and furnace $\left(100 \times \frac{\text{item } 31 \times 970{\cdot}4}{\text{item } 33}\right)$ %	81·05

* The term "as fired" means actual condition, including moisture, corrected or estimated difference in weight of coal on the grate at beginning and end.

† Corrected for inequality of water level and steam pressure at beginning and end.

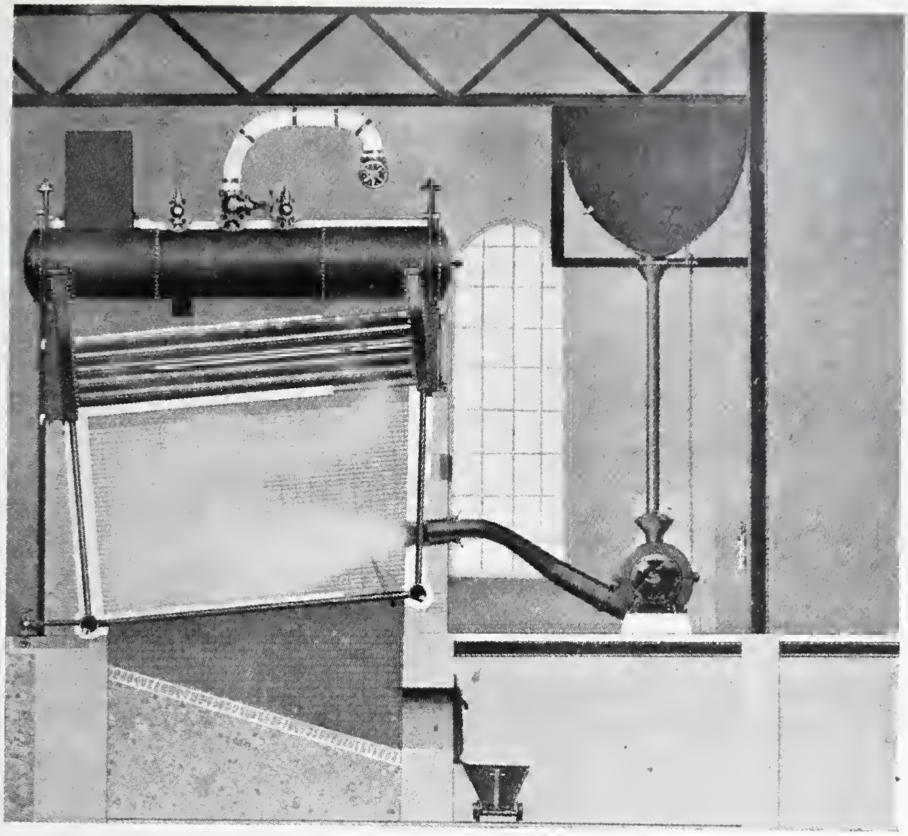


FIG. 226.—ERIE CITY MALLEABLE WORKS BOILER, SHOWING WATER-LINED FURNACE AND PULVERISER UNIT.

Erie City Malleable Works.]

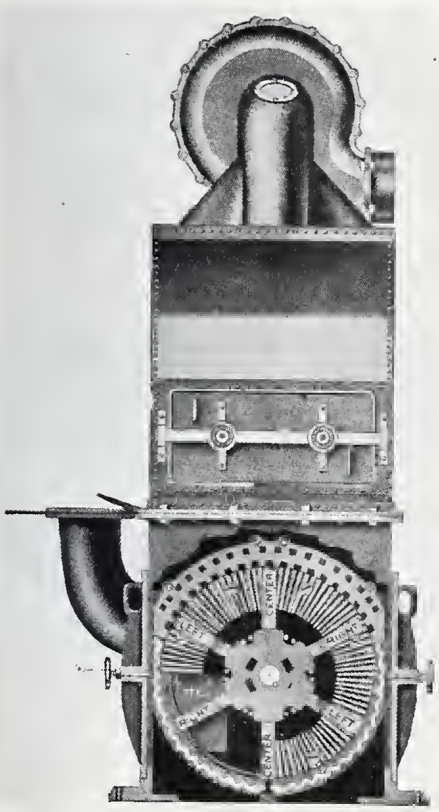


FIG. 227.—CROSS SECTION OF STROUD AIR SEPARATION PULVERISER UNIT.

E. H. Stroud & Co.]

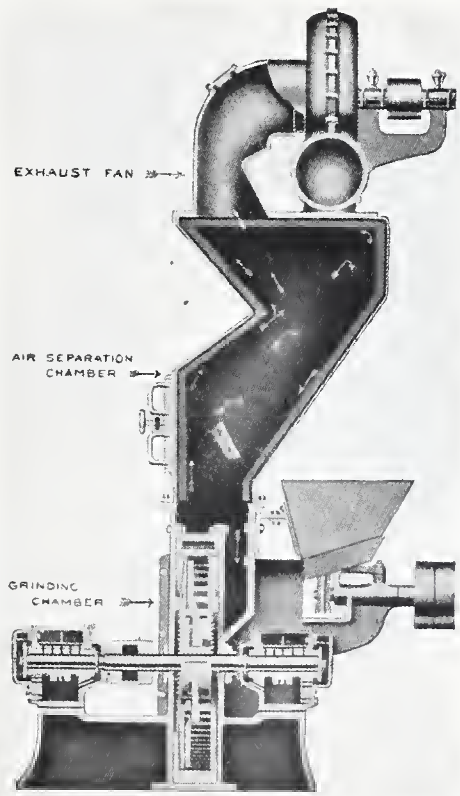


FIG. 228.—LONGITUDINAL SECTION OF STROUD AIR-SEPARATION PULVERISER UNIT.

[*E. H. Stroud & Co.*

[*To face p.* 380.

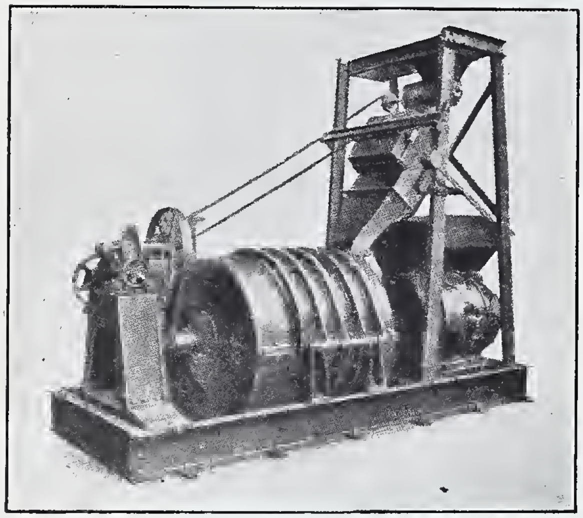


Fig. 229.—Side View of Walther-Farner Self-contained Pulveriser Unit.

Braunkohle.]

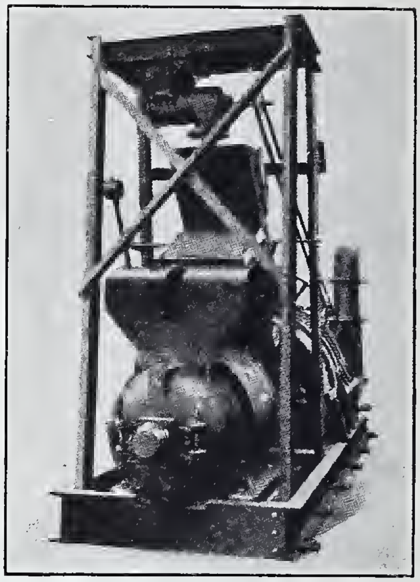


Fig. 230.—Motor End View of Walther-Farner Pulveriser Unit.

[*Braunkohle.*

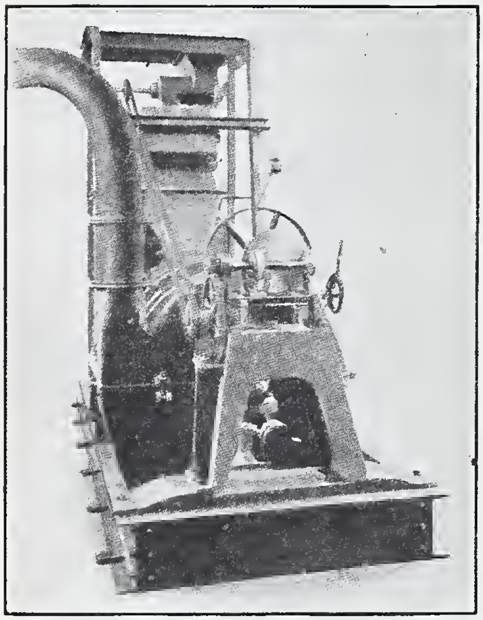


Fig. 231.—Fuel Regulator End of Walther-Farner Pulveriser Unit.

Braunkohle.]

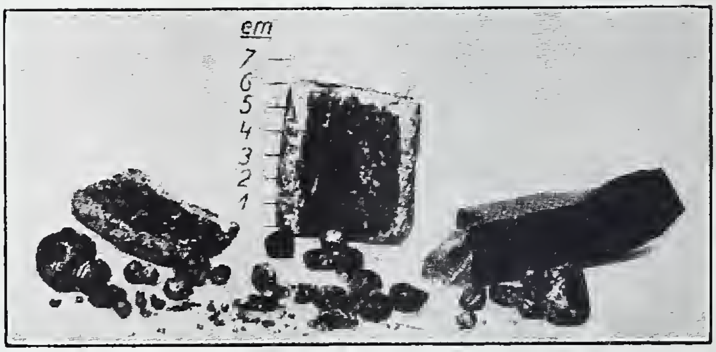


Fig. 231*a*.—Large Lumps and Small Pieces of Iron taken from a Walther-Farner Pulveriser Unit.

[*Braunkohle.*

Fig. 226 shows the general arrangement of pulveriser and horizontal water-tube boiler, with the special Seymour furnace, which enables the ash and slag to pass through a central longitudinal hole in the " hot pavement " bottom of the furnace into the ashpit underneath. The furnace is so constructed as to form a part of the circulatory system of the boiler. The water circulating through the tubes and headers which form the structure of the furnace keeps the furnace temperature in the vicinity of the refractories below their melting point, thus preventing their destruction. The heat absorbed by the tubes is used in the generation of steam by the boiler. It is claimed that, by the use of this furnace, it is both practicable and possible to maintain higher furnace temperatures than in the ordinary type of furnaces, and to burn the coal with from only 5 to 10 % excess air.

The " Stroud " Unit.

The Stroud self-contained unit is another type of small self-contained pulveriser apparatus, and is shown in Figs. 227 and 228. This apparatus belongs to the disintegrator class of machines. Coal of $\frac{1}{2}$ to 2 in. cube can be fed into the pulveriser. The lumps are thrown against each other and against the rough-toothed lining plates by the rapidly revolving beaters. When pulverisation has taken place, the dust is extracted by means of an exhausting fan, fineness depending upon the speed of the latter and the velocity of the air current through the grinding chamber. Coarse particles fall back into the grinding chamber.

The " Walther-Farner " Unit.

A self-contained pulveriser unit of the latest German design is shown in Figs. 229, 230, 231. This is the Walther-Farner pulveriser mill and complete self-contained equipment, the whole of which has been designed so as to make the plant as simple as possible. The most important part of the plant is the mill, which is of the high-speed centrifugal type fitted with cast-iron casing and steel lining; on the main shaft are carried several discs, each supplied with six grinding plates. Each disc revolves in a separate chamber, and the discs are connected with each other by a hollow drum concentric with the inner shaft. This drum is provided with apertures on its circumference, and is closed at one end, but at the other it is connected with the suction aperture of an exhausting fan wheel fixed on to the main rotating shaft.

The fuel fed into the mill at the closed end of the drum is acted on by the beaters, which are reinforced with manganese steel plates, and the fuel is hurled against the outer lining with great velocity and becomes rapidly pulverised. At the same time the fan induces a suction in the hollow drum in opposition to the centrifugal force acting on the particles of fuel in the interior of the mill. The suction of the fan being capable of regulation, it is possible to achieve a simple sifting action to separate the fine powder from the coarse fuel, the latter being carried along the beater chambers till it is also sucked through the apertures of the hollow shaft in the form of powder. In this manner it is claimed that many of the recognised defects of ordinary centrifugal mills are avoided.

The fuel is fed into the mill by means of a spiral feeder, and any degree of fineness can be obtained, equal to the product of large mills.

Fig. 232 shows a complete plant for boiler firing.

It does not matter if small iron pieces are fed into the mill with the fuel, wire nails, screws and nuts are not harmful—in fact Fig. 231*a* shows pieces of iron taken from a mill, the two large pieces being sections of angle iron.

The " Apco " Unit.

An American self-contained unit—the " Apco unit "—has been developed by the American Pulveriser Co. of St. Louis, Mo., U.S.A., a description of which has

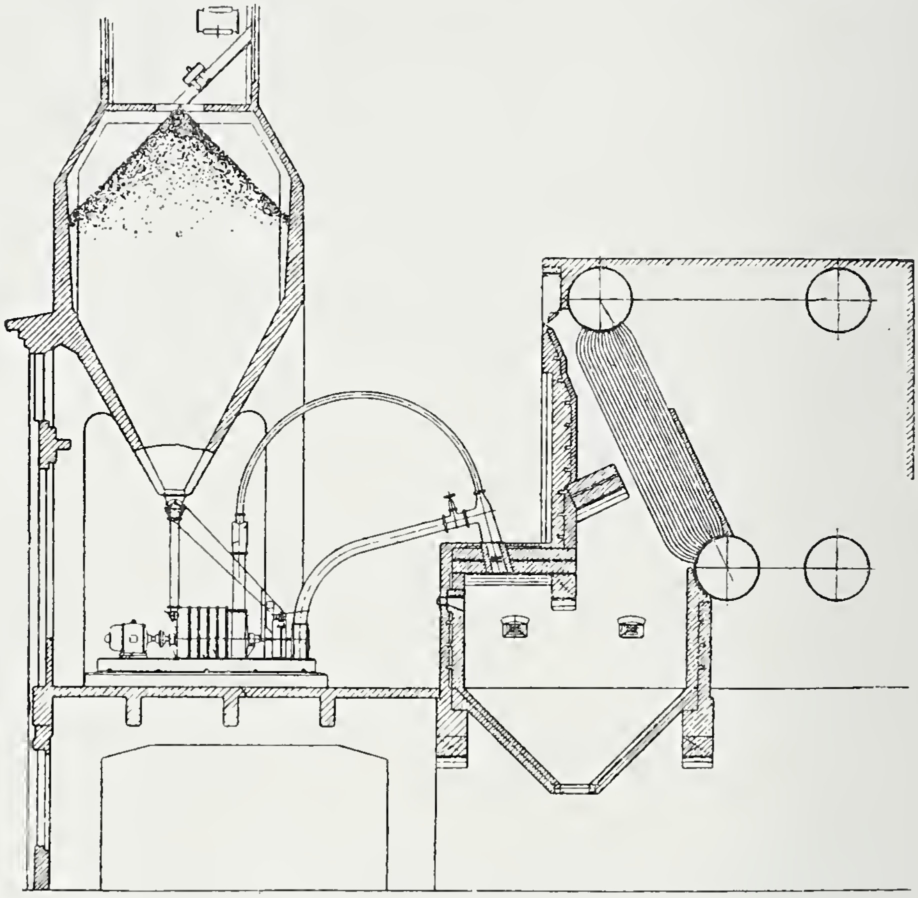


FIG. 232.—Walther-Farner Pulveriser as arranged for Firing Boilers.

appeared in the technical Press, the following illustrations and details having been taken from *Power*, May 1st, 1923 :—

With this unit, and when the moisture in the coal exceeds 3%, a tower dryer, which may also function as a bunker, utilising the waste gases of combustion, is desirable. Fig. 233 shows the arrangement of the equipment, including the dryer, and the general design of thc furnace, and in Fig. 234 the preparation plant is shown in more complete deatil.

The pulveriser, which is of the ring type, is motor-driven at a speed of 600 r.p.m. It is supplied with coal, crushed to $1\frac{1}{4}$ in. or smaller by an eccentric-driven feeder, hand regulated, or, if desired, by a motor-driven feeder regulated by maximum

and minimum solenoids inserted in the supply circuit to the pulveriser motor. Overfeeding loads up the pulveriser, causing a flow of current greater than normal, so that the maximum solenoid functions and stops the feed. When the load has lightened and the flow of current is less, the minimum solenoid starts the feeder.

About 30% of the air required for combustion enters through an inlet in the suction elbow connecting the pulveriser and the expansion chamber. Part of it passes down on one side of a deflection gate in this elbow into the pulveriser, while the remainder enters the expansion chamber. The air drawn into the pulveriser is almost immediately forced up into the expansion chamber at the side of the

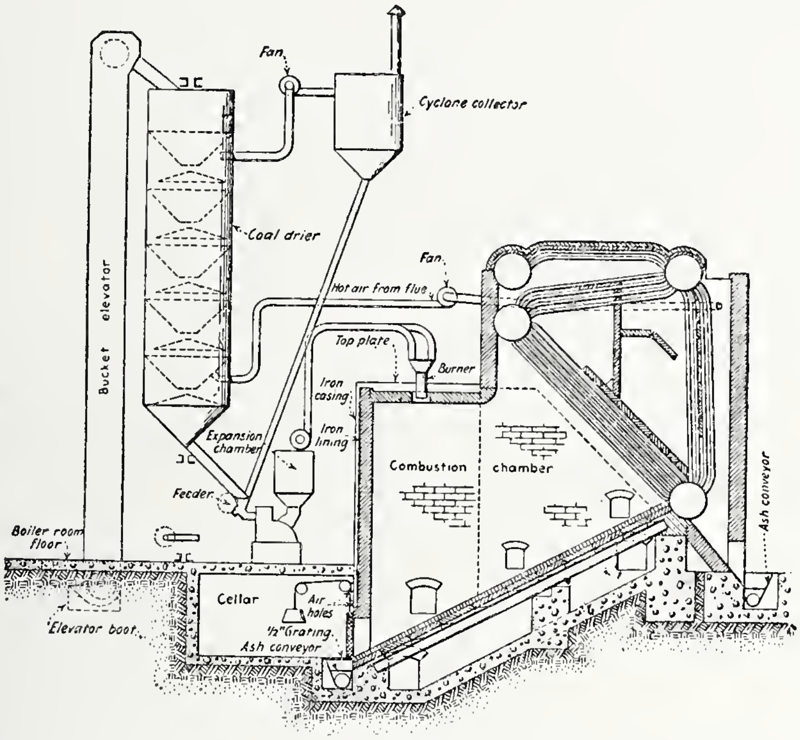


FIG. 233.—The Apco Self-contained Pulveriser Unit, showing Coal Elevator and Static Raw Coal Dryer.

(*Power*, May 1, 1923.) (*American Pulveriser Co.*)

deflection gate opposite to its entrance, carrying with it the finely pulverised coal. Deflection gates at the outlets to the expansion chamber prevent the coal-air mixture carrying straight through. With the sudden increase of volume upon entrance to the expansion chamber, the velocity of the mixture slows down, dropping the coarser particles of coal that have been carried along with the current, or propelling into the chamber by centrifugal action, and allowing them to return to the pulveriser for further grinding through the opening at the inlet side of the deflection gate. At the air inlet a small receptacle is provided to catch and retain the tramp iron that may have been carried through the machine.

From the expansion chamber double-fan units, with the driving motor placed between the two fans of a unit, draw the fuel mixture and deliver it through the burners vertically downward into the boiler furnace. Each pair of fans deliver to

a single burner, the two delivery lines being brought together in the funnel-shaped top of the burner, where the two streams, of equal velocity and density, meet and produce a swirling action tending to commingle thoroughly the coal dust and the air, so that a uniform mixture is delivered into the furnace at relatively low velocity. The lower end of the burner is shaped to give the proper direction and form to the fuel stream. Because of this low velocity and the premixing of the air and the coal dust, a special hot zone is formed about 10 in. below the mouth of the burner. All particles of dust must pass through this zone, and in doing so are expanded and disintegrated, to be brought into contact with the necessary amount of air.

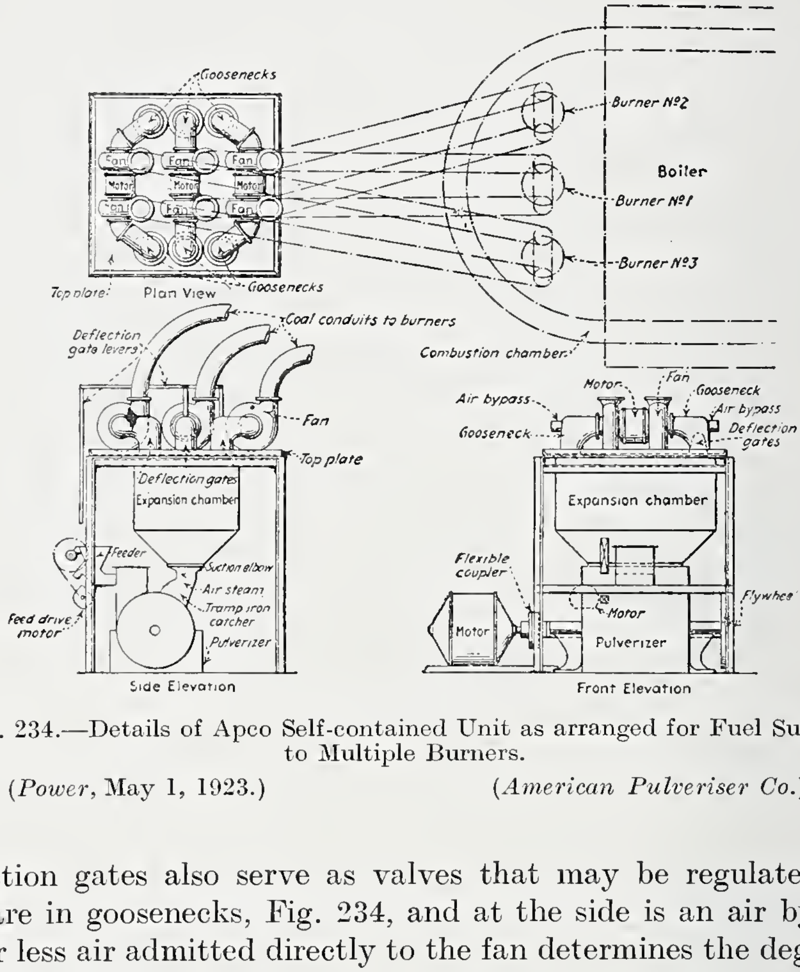


Fig. 234.—Details of Apco Self-contained Unit as arranged for Fuel Supply to Multiple Burners.

(*Power*, May 1, 1923.) (*American Pulveriser Co.*)

The deflection gates also serve as valves that may be regulated to vary the flow. They are in goosenecks, Fig. 234, and at the side is an air bypass, through which more or less air admitted directly to the fan determines the degree of vacuum in the expansion chamber.

The dryer is of simple form, consisting of a vertical cylinder which may also be used as a bunker. As usually made it is some 40 ft. in height, and within the shell is a series of hopper bottom guides alternating with low cone-shaped discs, the latter being secured to a common vertical shaft which may be rotated at the desired speed, or held stationary to retain high-moisture coal for a comparatively longer period.

While the discs are cone-shaped, the slope is well within the angle of repose of the coal, so that scrapers attached to the shell must remove it before it passes on

down to the next disc, and finally out to the pulveriser feeder. Spreading the coal out in this way brings it into intimate contact with the hot gases of combustion which enter at the bottom of the tower, and pass up through the coal, and through perforations in the guide plates. At the top of the dryer a second fan draws off the gases, making delivery to a cyclone collector, which returns any fine coal that may have carried over to the feeder, and vents the gases to atmosphere. The dryer will store about 15 tons of coal and, depending upon the moisture content, will dry 3 to 5 tons an hour.

The " Vickers-Griffin " Unit.

Another of the recent practical designs of self-contained unit that has been brought to the knowledge of the author is the Vickers-Griffin machine. In this there are several good features. The equipment forms a very compact unit, complete with air-separator section. Fig. 237 shows the general arrangement of the machine with

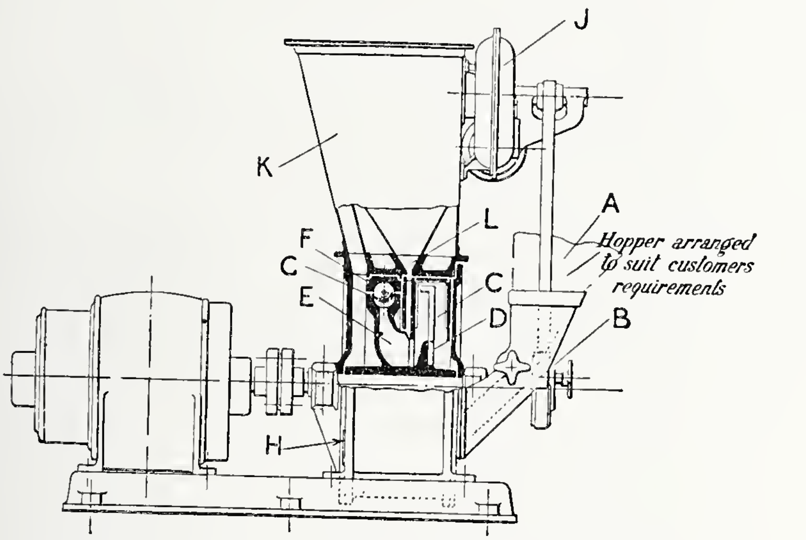


Fig. 235.—Sectional View of Vickers-Griffin Self-contained Pulveriser Unit. (*Vickers, Ltd.*)

air-separator fan, which is advantageously placed on the delivery side of the separator section, and not, as is more usually the case, between the pulveriser discharge and the separator inlet. Thus the fan wheel is only called upon to extract the fine finished product.

On reference to the sectional view of this equipment shown in Fig. 235, it will be seen that the pulveriser chamber C is divided into two parts. In the one, the breaking down of the fuel to small granules is effected by means of the rotary beater arms D. The granulated coal then passes into the pulverising rotor E, which is made in the form of a hollow armed wheel, the periphery of which is a **U**-shaped trough forming, with the grinding ring F, a partially closed path for the grinding balls G. The granulated coal passes into the pulverising zone through ports in the **U**-shaped trough of the rotor. The balls are carried round with the rotor by means of pushers, and are kept in contact with the grinding ring by centrifugal force.

The feed from the hopper A to the machine is capable of regulation by means of a control gear B, and the degree of fineness is dependent upon the amount of air drawn in at H, and thus through the machine by means of the exhausting fan J. Any coarse particles of fuel which may be drawn into the air separator K fall by gravity through the passage L into the machine for regrinding, and do not pass through the fan.

The units are made in six sizes, from a capacity of $\frac{1}{4}$ up to $2\frac{1}{2}$ tons per hour. One feature of exceptional interest is the low speed at which the rotor revolves, the speed being only about 250 r.p.m. for the smallest size.

In this machine are embodied efficient air separation, slow speed, initial breaking-down chamber, ball and ring pulverising elements, adjustable feed and adjustable discharge, so that both supply and degree of fineness desired are under control, all of them good features in a self-contained unit. The unit, moreover, will satisfactorily pulverise fuel containing up to 10% of moisture, and in this respect functions just as well when fed with moist coal as in the case of the Atritor unit.

The " Brierley " Unit.

The " Brierley " Pulveriser Unit, Fig. 236, is yet another Self-contained Machine which has appeared very recently and is already giving good results. It is the invention of H. G. Taylor and P. Smith.

At a Staffordshire Iron Works these Units have been applied to forge furnaces, the dimensions of which are : 10 ft. long, 5 ft. 6 in. wide, and 4 ft. 6 in. high.

The furnaces were formerly hand fired. The only alteration found necessary in effecting the change over to pulverised coal firing was the removal of the furnace bridge wall, thus utilising the old grate area as the present combustion chamber.

The Unit illustrated has a capacity of 1000 lb. of coal per hour, and occupies a floor space of approx. 3 ft. by 3 ft. 6 in., and the height over the coal hopper is about 5 ft.

It will be noticed that this machine is of the vertical Spindle type. The coal is fed into the hopper and falls into the grinding zone, in which the fuel is pulverised between a series of fixed and revolving pins. Below the bottom revolving plate and to this plate is fixed a fan wheel by means of which a partial vacuum is produced in the machine, the pulverised coal coming from the grinding zone only mixing with the air supplied in this manner. No fuel actually passes through the fan. In this way the mixture is conveyed to the furnace burner.

Air is admitted to the machine through the duct shown, the quantity being regulated by the adjustable slide. In like manner the quantity of fuel fed into the pulverising zone is under control—thus the air and fuel can be regulated at will to suit the firing conditions.

The above notes have been taken from an account appearing in the August 31, 1923, issue of the *Iron and Coal Trades Review*, in which article the following information is also given :

Power consumption is considerably reduced owing to the fact that pulverisation takes place in a partial vacuum. The air for combustion is mixed with the coal

only after pulverisation is complete, no powdered fuel passing through the fan—a factor which tests have proved to effect a reduction in driving power of from 15 to 25 %.

The machine is primarily designed to use the smallest class of coal—*i. e.* " dust " —and larger lumps which find their way into the hopper are automatically reduced before final pulverisation. The screen-plate within the hopper prevents the passage

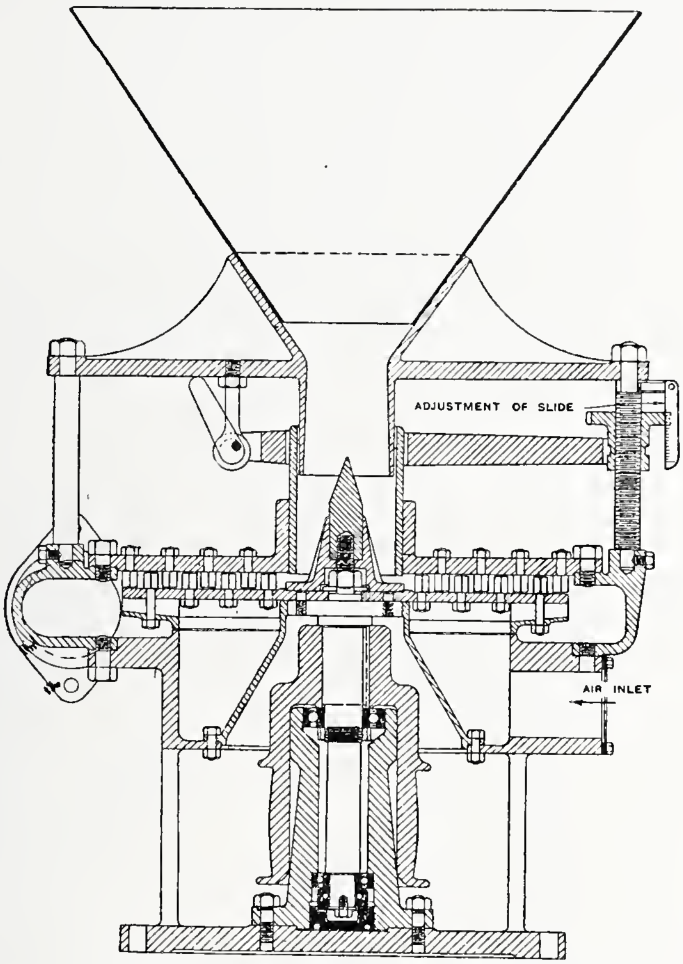


Fig. 236.—Sectional View of the Brierley Self-contained Pulveriser Unit. (*Iron and Coal Trades Review.*)

of iron or other foreign material into the pulverising chamber. The machine is capable of dealing with fuels containing up to 10 % of moisture; obviously, however, the dryer the fuel the better will be the results obtained.

The following tests on three separate days are interesting :

(*a*) 350 lb. of coal ground per hour—power, 7·3 units per hour.

(*b*) 840 lb. of coal ground per hour—power, 7·8 units per hour.

(*c*) 1824 lb. of coal ground per hour—power, 8·4 units per hour.

The average fineness of pulverisation was 94·4 to 90·2 % through 100 mesh.

In the case of (*c*), this test was made merely to determine how much coal could

be put through the machine, which, as already stated, was only designed for 1000 lb. per hour. It will be also understood that the power results fluctuate slightly owing to the varying moisture content of the coal.

L'Atomiseur " Rex."

One of the most popular self-contained pulveriser units in France to-day is the Atomiseur " Rex " supplied by E. Maury of Paris.

The machine is illustrated in Figs. 238, 239. The first view shows the machine closed and the second the machine open.

There are several very special features regarding this unit. The grinding members do not consist of metallic surfaces, but of carborundum discs, the speed of rotation of which (about 1,500 r.p.m.) can be accurately governed by means of the variable speed cone gear shown.

It is claimed that the fineness of product is absolutely constant and the mixture of pulverised fuel and air required for combustion is automatically regulated.

It will be seen that the machine can be instantly opened out for inspection of the interior. Another useful feature of the unit is the totaliser which records the amount of fuel fed into the machine, so that it is an easy matter to see just how much fuel is being burned in a furnace.

The quantity of air drawn into the unit is controlled by the setting of the air slide seen at the front of each view of this pulveriser. Many installations have been made at important works in France, and units are in operation in neighbouring countries and as far afield as Esthonia. When necessary an extension of the fuel hopper is employed and made in such form that this extension constitutes a fuel dryer through which hot gases are passed in order to remove excessive moisture in the coal.

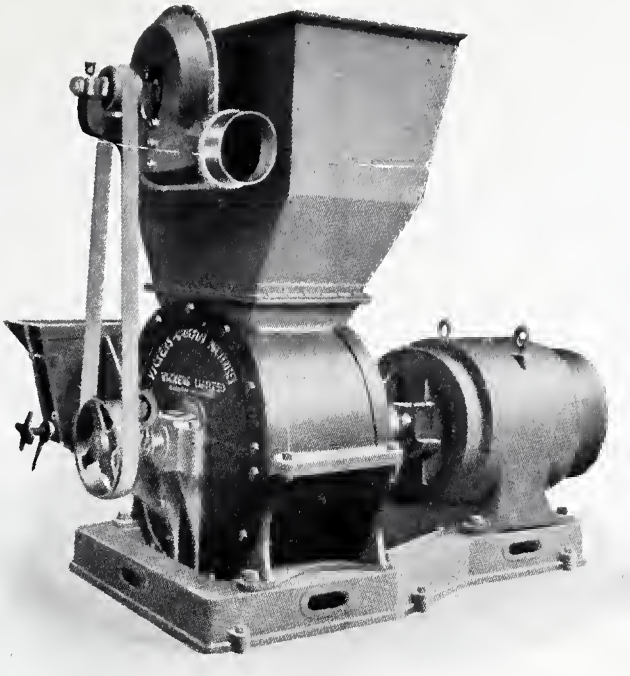


FIG. 237.—VICKERS-GRIFFIN SELF-CONTAINED PULVERISER UNIT.

Vickers, Ltd.]

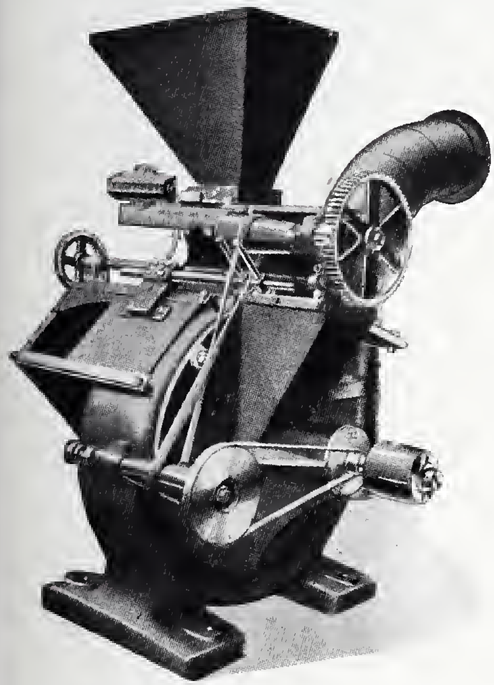


FIG. 238.—L'ATOMISEUR "REX" (CLOSED).

E. Maury, Paris.]

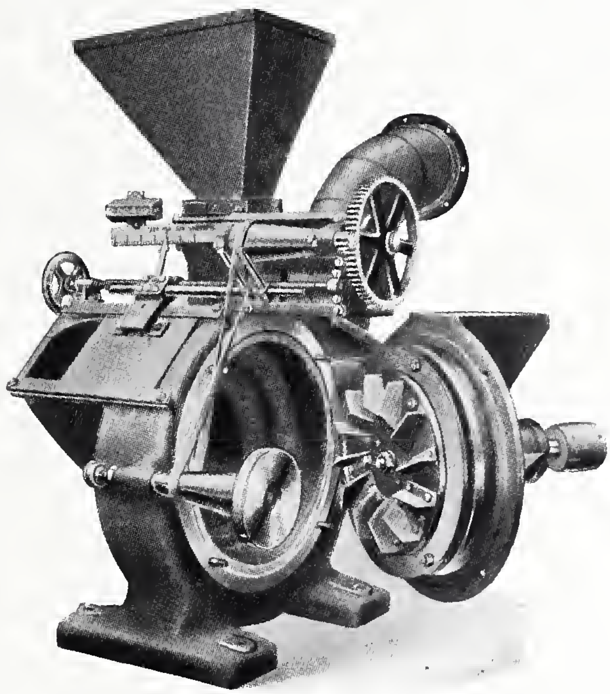


FIG. 239.—L'ATOMISEUR "REX" (OPEN).

[*E. Maury, Paris.*

[*To face p.* 388.

CHAPTER XVII

PULVERISED COAL AS A FUEL FOR SHIPS

General Considerations—Two Classes of Vessels Reviewed

In the direction of the practical application of pulverised coal for marine boilers comparatively little further progress has yet been made, but the interest shown by some of the leading shipping companies in Europe during the two years 1919–20 suggests that the use of pulverised coal for firing boilers on board ship is quite likely to be adopted, under certain circumstances, in the near future. Developments in this direction must of necessity be slow, and the general use of powdered coal on board ship, if this should ever result, will not take place until some further improvements have been made, and, it is hoped, altogether novel and more efficient methods of pulverisation on board have been successfully evolved.

Once it becomes possible to substitute powdered coal firing for hand firing, the appalling conditions which so frequently exist in the stokehole, more especially in tropical climates, will for ever be removed.

In 1915, it was reported that the Pacific Coast Steamship Co., of Seattle, Washington, operating passenger and freight steamers between San Francisco and Puget Sound Ports, etc., intended to charter a tug to be fitted up for burning pulverised coal. Information has not been sought as to the results of these experiments, and no actual progress in regard to them appears to have been made public.

One of the most important applications recorded of late was made during the war period to one of the boilers of H.M.A.S. *Skylark* by Engineer Commander Brand, who ran his pulverised coal-fired boiler all through the war years on pulverised coal taken on board and stored in closed bunkers.

General Considerations.

There are some vital questions to be solved before pulverised coal can be successfully used as a marine fuel, to which both full consideration and actual trial must be given, in order to determine the most advantageous method to be adopted for passenger, cargo, warships, tug-boats, and river craft. Some of these various considerations are :—

(*a*) Whether the pulverised coal to be used can be shipped in bulk, and kept without danger for the period of the voyage.

(*b*) Whether complete equipment, including dryers and pulverisers, should be installed, so as to use any coal at any port.

(*c*) Whether previously dried coal should be bunkered, and pulveriser mills only be installed on board ship.

(*d*) Whether the use of the self-contained unit pulveriser and burner, either with or without dryer, would be successful.

Here, again, it is possible that the Trent or other such system of fuel treatment may be a means of providing certain qualities of pulverised fuel which would be eminently suitable as a marine fuel.

The answers to all these questions, and the solution, no doubt, of many other details or difficulties not as yet foreseen, lie in the future.

Certain trials conducted on U.S. Scout Patrol Ship *Gem* with powdered coal demonstrated that equal speed could be obtained with steam generated in one boiler fired with pulverised coal as with two oil-fired boilers. At the same time a CO_2 content of from 14 to 16 % was maintained when using coal dust.

There is an extremely important field for investigation in this direction, and it may eventually become possible to pulverise and use ordinary bunker lump coal without having to rely upon shore pulverisation and the bunkering of coal in powdered form. Such equipment as the self-contained dryer and pulveriser "Atritor" or "Rex" machine (see Figs. 217 and 239) appears to point to a possible solution of many of the difficulties at present barring the way to further progress.

The use of the self-contained pulveriser units on board ship should overcome the objections both as to excessive space occupied, and noise and vibration.

The greatest objections to the installation of complete plant on board ship are: (1) the space taken up by rotary coal dryers and pulveriser mills, (2) the noise and vibration caused by the mills. It is quite within the bounds of possibility that efficient centrifugal coal dryers of the continuous discharge type may be found satisfactory for the extraction of water from the coal. These would occupy relatively small space, and may not be required at all, seeing that present-day self-contained pulveriser units can function quite efficiently with raw coal containing up to 10 %, and in some cases 15 %, of moisture.

The installation of pulverised fuel equipment upon large vessels at the present stage would be folly. It is useless to attempt to run before one can walk. Developments of the immediate future should be confined to small trading vessels or tugs, for which experimental equipment will not be unduly expensive.

Two Classes of Vessels Reviewed.

In order to give some idea as to the main considerations which must receive careful examination before even an experimental equipment can be installed, we will assume for the sake of illustration that it is proposed to apply pulverised coal firing to the vessels of a company operating from a home port, and that the vessels are of two classes, as mentioned below. Such a proposition was, in fact, considered and reported upon by the author.

Class A. Vessels ranging from 500 tons to 900 tons burthen engaged in coasting trade, the vessels being eqiupped with engines from 300 h.p. to 1000 h.p., and the length of trips from the home port being, say, 24 hours to about 80 hours as a maximum. The total fuel consumption for present hand-fired boilers for all purposes on these trips varies from 15 to 60 tons of coal. It may be that passengers are carried on these vessels, so that undue noise in the engine and boiler-room must be prevented, and the deposition of ash dust over the decks from the funnel avoided.

Class B. Vessels of a smaller type, ranging from 100 to 300 tons burthen,

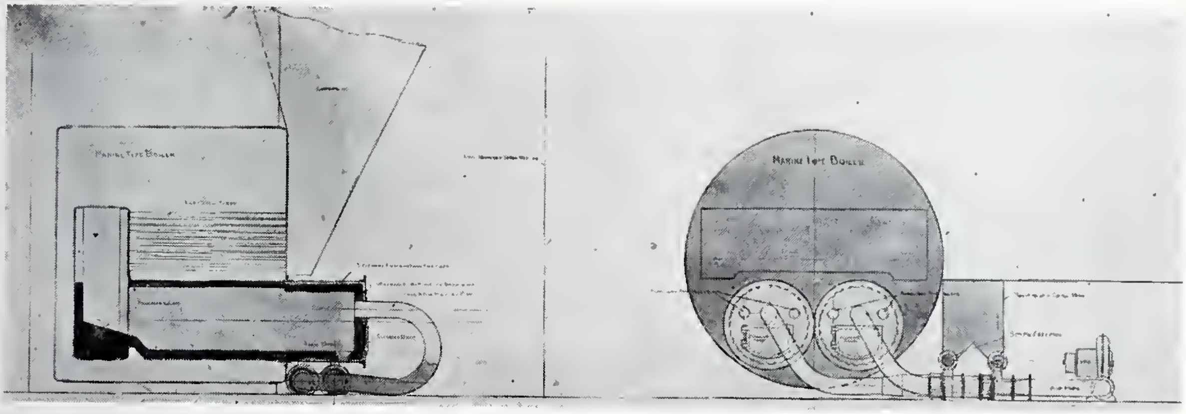


Fig. 240.—Section of Scotch Marine Type Boiler, showing Combustion Chamber lined for Pulverised Coal Firing, with Ash-clearing Doors and Slag Holes at Front.

[*To face p.* 390.

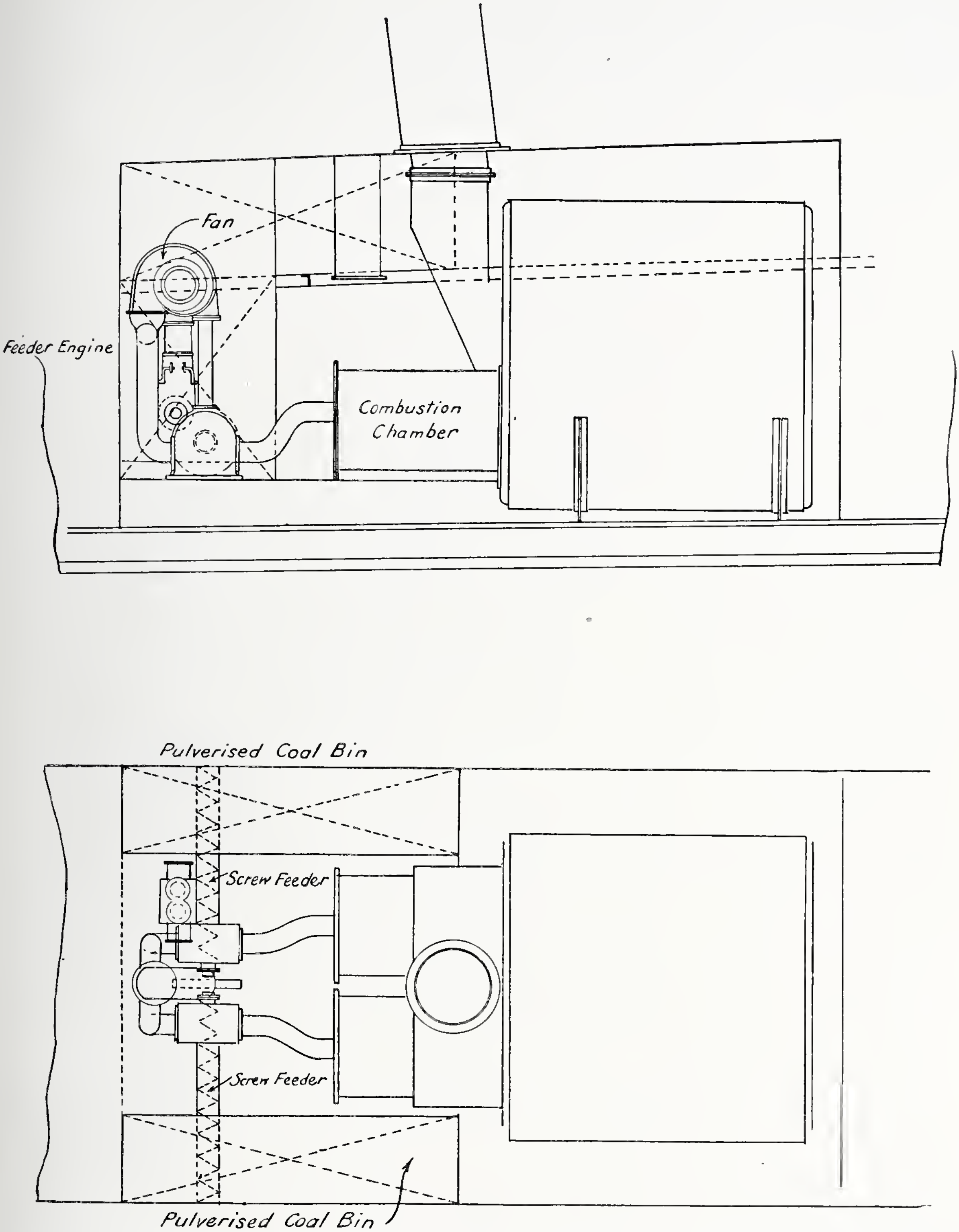


FIG. 241.—Suggested arrangement of Fuel Bunkers on Small Vessel, showing position of Fuller "Locomotive Type" Feeder Units and Screw Conveyors.

such as harbour tug boats or small vessels engaged in local coastal trading, the engines being from 100 h.p. to 300 h.p. Length of trip, say, from 4 to 18 hours' duration, with a coal consumption for hand firing per trip varying from 0·5 to 5 tons. It is, of course, essential that any external combustion chambers (see

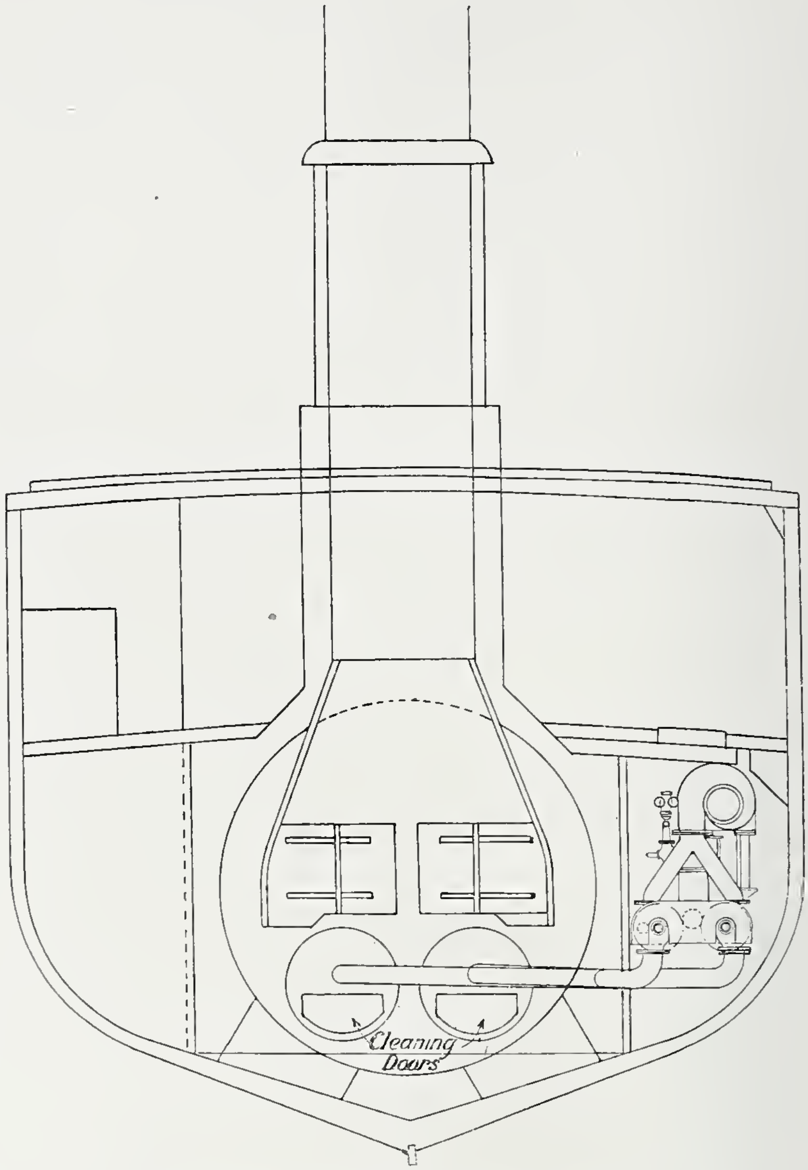


Fig. 242.—Suggested Arrangement of Burner Pipes and Fuller "Locomotive Type" Feeder Unit for Small Vessel.

Fig. 240) or firing gear to the boilers must be strong and snugly built, in view of the rough conditions of marine service, and the very small space available. Easy access to the bottom manhole of the boilers must be assured. There must be no undue amount of heat radiated from the outside of the combustion chamber into the boiler room.

As the furnace tubes on the various boilers of the two classes of vessels vary

in diameter from about 33 in. to 40 in., it will be feasible to adopt one standard size of burner gear and equipment.

Existing coal bunkers can be rendered suitable for the pulverised coal without the use of independent new bunkers for this purpose, the existing bunkers being made dust- and air-tight by electric welding.

Class A vessels would probably have a supply of continuous current at 110 volts, but no electric current would be available on class B vessels, in which, therefore, petrol electric sets must be installed.

A pulverised coal storage tank or bin would be erected on the edge of the wharf

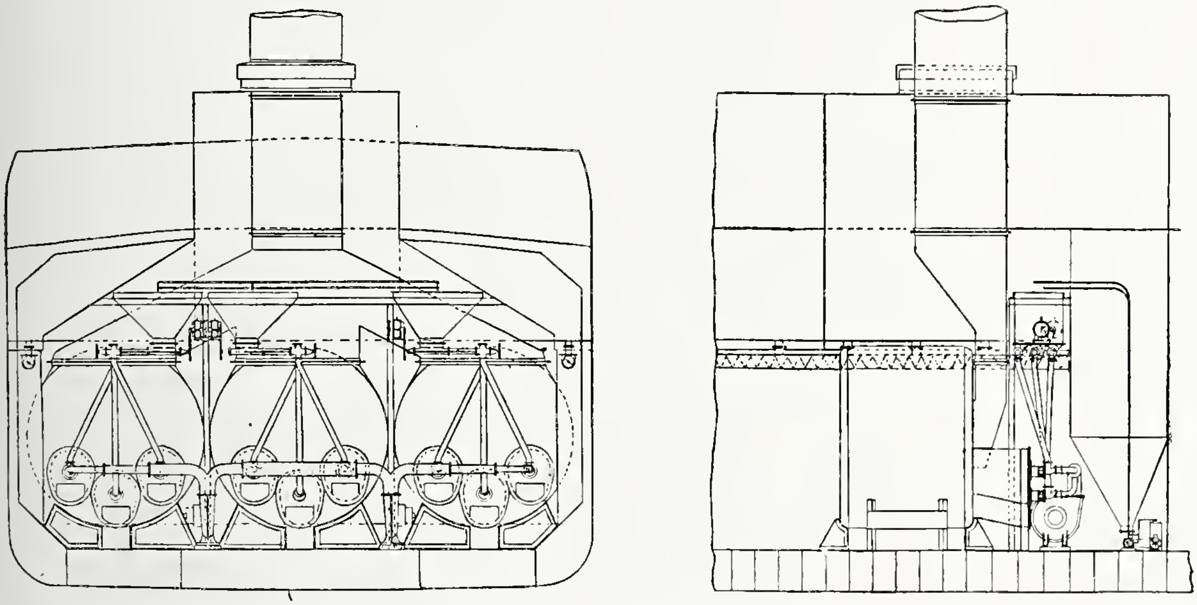


FIG. 243.—Suggested Arrangement of Subsidiary Fuel Bins at Boilers supplied by Fuller-Kinyon Pump from Main Storage, showing Positions of Screw Feeders and Air Supply Fans.

for fueling the vessels, in addition to a small distributing boat fitted with a tank and suitable equipment for delivering the pulverised coal into the bunkers, should this be necessary.

In any proposed scheme for using pulverised coal on board ship some of the many questions that must be answered, are stated in the following outline of general information given for these two classes of ships. Answers are tabulated for both classes of vessels.

Illustrations relating to vessels of these types, showing positions of pulverised coal bunkers, feeders and burners, and for the larger ships, complete pulverised coal equipment on board, are shown in Figs. 241, 242, 243 and 244.

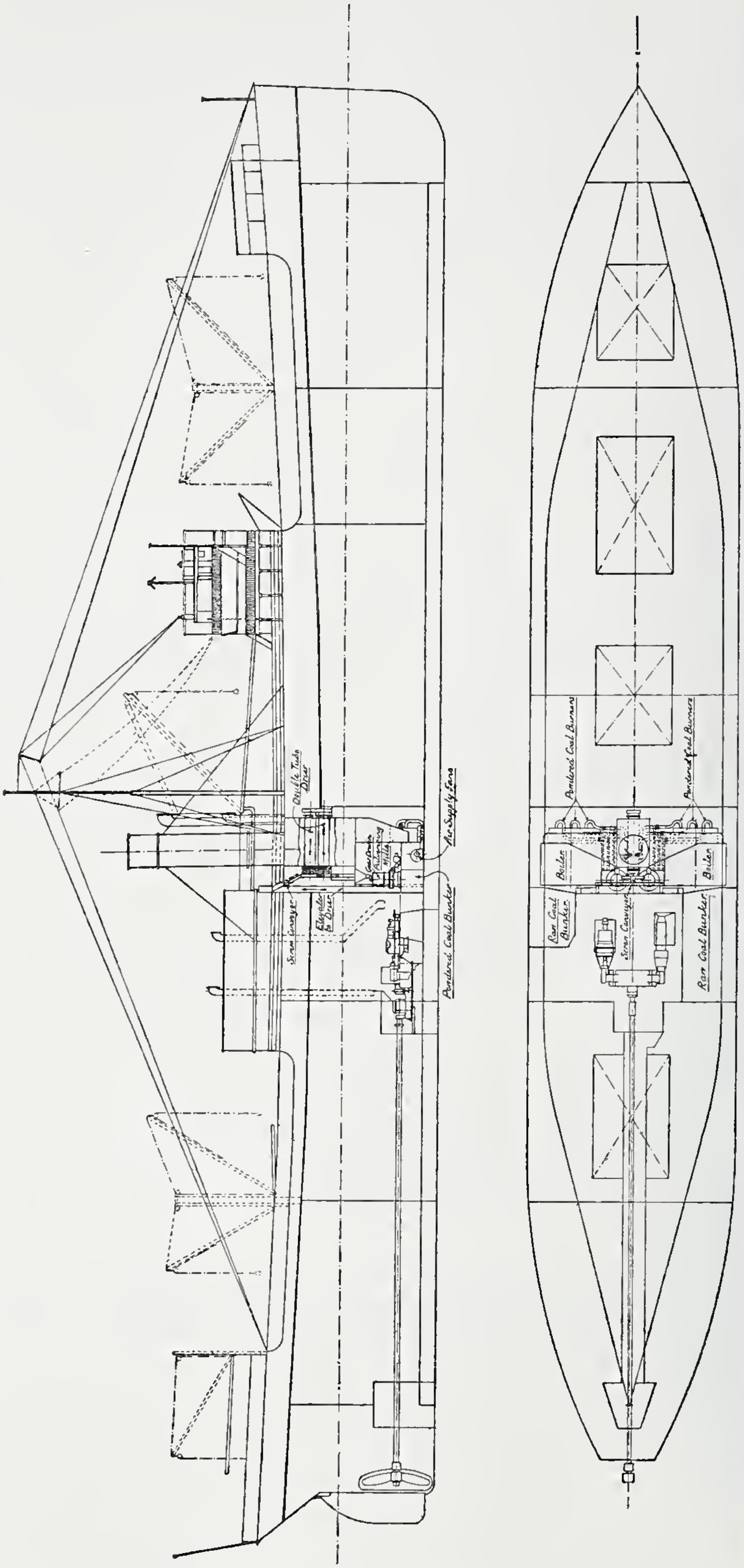


Fig. 244.—Complete Installation of Rotary Coal Dryer, Pulveriser Mills Feeders, Fans and Burners as proposed for a Ship of 9000 Tons.

Information Desired by the Owners.	Suggestions and Replies. Class A. Vessels.	Suggestions and Replies. Class B. Vessels.
(1) Could the vessels in Class A be bunkered with completely prepared pulverised coal ?	There is no reason why such ships should not be bunkered with pulverised coal for trips of 24 to 80 hours. There would be no danger of spontaneous ignition with normal grades of fuel (except perhaps lignite) if due precautions are taken. Pulverised coal has lain in bunkers containing 60 to 80 tons for months without any overheating or ignition. During the war an Australian naval vessel (H. M. A. S. *Skylark*) was run for two or three years with one set of boilers fired with pulverised coal, this fuel being bunkered in port. Sealed bunkers were fitted and inert gases from the chimney were used to fill the space at the top of the bunkers as the coal level fell. Such special precautions are, however, not considered essential in ordinary cases. There would be no danger in leaving pulverised coal in bunkers for a week, providing the coal is bunkered cold and perfectly dry. It is only when pulverised coal is bunkered warm and moist that spontaneous ignition will occur with ordinary coal. If hot coal is put into cold bins, sweating will take place, and conditions suitable for spontaneous ignition are then set up. Arrangements should be made to allow the pulverised coal to become quite cool in the storage on shore before bunkering the ships. In short, it may be said that, with reasonable precautions and without undue expense, spontaneous ignition of the pulverised coal can be prevented.	Recommendations would be the same as for Class A vessels, the conditions in this case being more easily met. A modified burner equipment on the lines of locomotive equipments could be used, the screws being driven by a small steam engine, which would also operate a turbo fan for the air supply. See Fig. 201.
(2) If ships of Class A are bunkered with crushed *dry* coal, could the final pulverisation be carried out on board	Under the conditions stated of trips of 40 to 80 hours' duration it would be inadvisable to instal any class of	For this class the supply of pulverised fuel direct to ships' bunkers is the best method to adopt.

<table>
<tr><th rowspan="2">Information Desired by the Owners.</th><th colspan="2">Suggestions and Replies.</th></tr>
<tr><th>Class A. Vessels.</th><th>Class B. Vessels.</th></tr>
<tr><td>with a small pulveriser or a self-contained impact pulveriser installed, taking into consideration the small space available on board, and the desirability of avoiding noisy operation, in view of passenger traffic ?</td><td>pulveriser on board the vessels. Machines of the self-contained impact pulveriser class are usually unsuitable to meet the conditions of firing a "Scotch" marine boiler, owing to the very limited combustion area in which only fine dry fuel in pulverised form can be burned with success. Further, the space available is insufficient, and the avoidance of noise renders it all the more desirable to consider only burner units which will run without noise or vibration. The "Atritor" machine might be an exception.</td><td></td></tr>
<tr><td>(3) How much room is required for external combustion chambers ?</td><td>Only a small extension combustion chamber is possible. See Fig. 240 for proposed arrangement, and Figs. 241 and 242 for outline of burners proposed.</td><td></td></tr>
<tr><td>(4) Method of filling bunkers to be explained.</td><td colspan="2">This would be the same for both classes of vessels. As pulverised coal will normally flow like water, it is easy to connect the bottom of the storage tank on the wharf side with a flexible hose to the ship's bunkers, in the same manner as oil fuel would be taken on board, except that a return main for the displaced air from the ship's bunker to the top of the storage tank is advisable, in order to prevent the escape of coal dust. The flow of coal can readily be controlled by gate valves. If a small vessel is used to distribute coal to the larger vessels, this would be fitted with a coal-delivery system such as the Fuller-Kinyon pump shown in Fig. 104, driven by a petrol engine on board, or by an electric motor supplied with current through flexible cable from the ship to be fuelled.</td></tr>
<tr><td>(5) How can pulverised coal be kept free from moisture ?</td><td colspan="2">Pulverised coal bunkers should be built with an air space separating the outer wall of the bunker from the ship's side-plates. The sweating of the bunker plates will then be reduced or eliminated, and little or no absorption of moisture by the pulverised coal will take place.</td></tr>
<tr><td>(6) How much power will be required for driving the air fans and feeders ?</td><td colspan="2">All furnaces would be fitted with one 4 in. "Fuller" screw feeder, and one $4\frac{1}{2}$ in. dia. burner. The actual amount of power taken by each feeder would depend primarily on the amount of coal being supplied and the moisture in the coal, as more moisture means more power. It may, however, be stated that the maximum power required by the 4 in. size feeder is $\frac{1}{2}$ h.p. per feeder at normal full load. The amount of air required under pressure at the burners, when dealing with the amount of coal delivered by the 4 in. feeder at full load, is about 1400 cu. ft. per minute, which, under the required pressure, would absorb about $1\frac{3}{4}$ h.p. Say, a total maximum of $2\frac{1}{4}$ h.p. per burner installed.</td></tr>
</table>

<table>
<tr><th rowspan="2">Information Desired by the Owners.</th><th colspan="2">Suggestions and Replies.</th></tr>
<tr><th>Class A. Vessels.</th><th>Class B. Vessels.</th></tr>
<tr><td>(7) Will a heavy slag be formed in the combustion chamber ?</td><td colspan="2">Some 70% to 80% of the ash dust is carried out of the stack when working boilers with pulverised coal. The remaining 30% is deposited in the tubes and pockets of the combustion chamber, or becomes fused to the brickwork. Some clinker will, of course, be formed, but, with correct operation, it is possible to keep this from fusing into large pieces which would be difficult to remove. Cleaning doors, as large as possible, should be provided, so that cleaning out can be carried on without shutting down the furnace. There will naturally be less clinker than with hand firing, for a very much greater quantity of the ash is automatically ejected from the stack in the form of a very fine powder, so finely divided that it will not settle anywhere within a radius considerably more than the length of the Class B vessel. There would be no trouble due to ash settling on the decks, and much less labour would be required for disposing of the ashes when an equal amount of coal is being burnt, as in the case of hand firing. Stoke-hold conditions should thereby be greatly improved.</td></tr>
<tr><td>(8) Will the slag have to be chipped out, and if so how often ?</td><td colspan="2">With proper care and attention to firing conditions, it would not be necessary to clear out the hard slag formed more than once per 24 hours, but this depends to a certain extent on the rate of firing.</td></tr>
<tr><td>(9) What is the usual method of removing slag ?</td><td colspan="2">On land boilers it is possible to keep all the slag in a friable form, which can be knocked off with a light bar and removed with a rake. A small amount of the ash may fuse into a hard mass, but this need only be removed by chipping once in several weeks.</td></tr>
<tr><td>(10) How are the ashes removed ?</td><td colspan="2">All ashes (as distinct from slag or fused ashes) are in the form of a very finely divided powder, of which almost the whole amount passes out from the boiler stack.</td></tr>
<tr><td>(11) Can operations (9) and (10) be performed mechanically ?</td><td colspan="2">Ash which lodges on the tubes and in the smoke-box can be readily removed by air or steam jets. No successful mechanical means has yet been devised for removing slag or ashes from the combustion chamber. This must be done by hand, unless the ash slag is run out in liquid form, which might mean the fusion of refractory surfaces.</td></tr>
<tr><td>(12) Can the engine and boiler-room staff be reduced to one engineer and one man to look after the boiler firing and attend to the greasing of the engine, etc., thus doing away with the fireman in the case of Class A vessels ?</td><td>There need be only two men, the boiler man and the engine man, on the smaller Class A ships, and, say, one extra handyman on the larger ships.</td><td></td></tr>
<tr><td>(13) In the case of Class B vessels, can the engineer on watch supervise both the engine and boiler, without any other assistance ?</td><td></td><td>The engineer on watch can certainly attend to both boiler and engine, but a boy should be employed as a learner or helper in case of emergency.</td></tr>
</table>

<table>
<tr><th rowspan="2">Information Desired by the Owners.</th><th colspan="2">Suggestions and Replies.</th></tr>
<tr><th>Class A. Vessels.</th><th>Class B. Vessels.</th></tr>
<tr><td>(14) What is the minimum percentage of normal rating that the firing can be cut down to, whilst maintaining reasonably good working efficiency, when using pulverised coal ?</td><td colspan="2">When firing with bituminous volatile pulverised coal the flexibility and regulation obtainable are equivalent to oil firing, but, naturally, at very low rates of firing the volume of the combustion chamber renders high efficiency unobtainable. With anthracite low-volatile coals, the rate of firing probably cannot be reduced much below 25% of rating, on account of the higher furnace temperature necessary for igniting the fuel. In each case good working efficiency will be realised between 50% and 150% of normal rating, assuming the combustion chamber has been designed for normal rating.</td></tr>
<tr><td>(15) What is the maximum steaming capacity per square foot of boiler-heating surface when using pulverised coal ?</td><td colspan="2">This depends on several factors, including the type of boilers, condition of heating surface, inside and outside, class of feed water, etc., etc. It is sufficient to say that pulverised coal firing can equal, and in some cases surpass, the results obtained with oil firing.</td></tr>
<tr><td>(16) How much steam can be generated per lb. of coal of a given heating value ?</td><td colspan="2">This absolutely depends on steam conditions and feed-water temperature. This figure can be readily obtained for any fuel by allowing a 78% overall thermal efficiency from raw coal to steam delivered.</td></tr>
<tr><td>(17) Can preheating of the air be utilised with any advantage ?</td><td colspan="2">The air supply was preheated during the trials with pulverised coal on the U.S.S. Gem, with satisfactory results. It has, however, not yet been clearly established that the extra sensible heat carried in with the air supply is sufficient to compensate for the extra complication of air heaters. Moreover, the temperature of air supply must not be excessive when using highly volatile coals, otherwise distillation and coking of the coal may take place in the burner before it enters the combustion chamber.</td></tr>
<tr><td>(18) Is the combustion chamber built up of standard firebricks ?</td><td colspan="2">It should only be necessary to use ordinary standard firebricks, but special refractory blocks, although more expensive, might be used with advantage for certain parts of the lining.</td></tr>
<tr><td>(19) What storage capacity would be required in bunkers as compared with present capacity ?</td><td colspan="2">Existing bunkers should be of sufficient capacity, for, although pulverised coal only weighs about 37 lb. per cu. ft., as against 45 lb. for raw coal (a reduction of 18%), at least a 20% saving in fuel will be made as against hand firing.</td></tr>
<tr><td>(20) Is the system safe and reliable ?</td><td colspan="2">The system is as safe and reliable as oil firing or any other method of firing, provided a few reasonable precautions are observed, and that correct design and principles are embodied in the equipment used. First trials must, however, be made on the lines of experimental tests.</td></tr>
<tr><td>(21) Is the conveying system likely to choke ?</td><td colspan="2">In view of the extensive experience now gained with modern works equipments, no stoppage or failure is likely to occur, beyond the risks to which any type of rotary machinery is subjected.</td></tr>
<tr><td>(22) Can boiler tube spirals and ordinary "Diamond" blowers be used for removing ash dust ?</td><td colspan="2">Any ordinary type of dust remover can be used more readily than with ordinary firing, because there is no sticky soot with pulverised coal firing, all the ash on the tubes being in the form of a fine, loose, dry powder.</td></tr>
</table>

Information Desired by the Owners.	Suggestions and Replies.	
	Class A. Vessels.	Class B. Vessels.
(23) Must the pulverised coal storage tank at the wharf side be made of steel plate construction ?	The wharf storage tank for pulverised coal is preferably made of ferro-concrete or similar material, as there is then less chance of "sweating" and corrosion of steel plates by sulphur in the coal. Ample cooling surface should be provided in this storage bunker.	
(24) Must this tank be covered with heat insulation ?	No covering is needed; in fact, means should be provided for dissipating the heat in the coal stored in this tank as rapidly as possible.	
(25) How many men would be required for a plant to pulverise 22,000 tons of coal per year ?	Assuming the daily capacity to be 75 tons per 16 hours, and two $2\frac{1}{2}$-ton Fuller mills and one dryer to be used, two men per shift would be required in the mill-house proper on continuous duty. An extra man would probably be required to work the grab conveyor and give general help about the plant, or, say, a maximum of four men on the first shift and three men on the second shift each day, thus allowing for one additional man for one shift. No heavy manual labour or high skill is required for any of the duties about the plant.	
(26) What is the largest quantity of pulverised coal that can safely be stored ?	This cannot be answered. A number of different factors enter into the question, such as the quality of coal, method of storage, average temperature and humidity of atmosphere, design of storage bin, care experienced in operation, etc. It may, however, be said that, as a rule, provision need not be made for more than two or three days' supply of pulverised coal in the wharf or jetty supply bunker, and with reasonable precautions there is no danger of spontaneous ignition in this period, for almost any bulk stored.	
(27) Do the authorities object to locating the mill-house near the coal storage yard ?	Insurance companies have asked for no increase on ordinary fire risks, as a pulverised coal plant is less dangerous than an ordinary gas works or oil refinery.	
(28) Can it be said that the use of pulverised coal on board ship has passed the experimental stage ?	Comparatively little has been done with pulverised coal on board ship, up to the present, but, on the other hand, so much experience with this class of fuel has been gained in other applications, that this problem can be approached with every confidence. The most efficient and suitable types of bunkers, feeders, burners, pulverisers, and other equipment of a similar class, have been proved by experience, but the exaet arrangement of this equipment, to mcet the limited space available and special conditions on board ship, has yet to be definitely determined. No doubt, modifications of the present known equipment will be found advisable. This is particularly the case where pulverising and drying will be carried out on board ship. The problem, therefore, is to apply successfully well-established principles to a new set of conditions.	

APPENDIX

Combustion Data and Firing Efficiency (Tables 1 and 1a)—Steam and Gases (Tables II to VII)—Air Mixtures and Water Vapour (Table VIII)—Heat Contained in Metals at various Temperatures (Tables IX and X)—List of Complete Pulverised Coal Installations and Self-Contained Units in Various Countries (United States of America and Europe)—Bibliography (Articles and Publications from 1879 to 1923 in English, American and Continental Press)—Bulletins and Technical Papers on Fuel Subjects issued by the Department of Mines, Washington, U.S.A.

Combustion Data and Firing Efficiency.

One B.Th.U. or British Thermal Unit is the amount of heat required to raise the temperature of 1 lb. of water through 1° F., at 60° F.

One kilogram Calorie is the amount of heat required to raise the temperature of 1 kg. of water through 1° C. at 15° C.

One Calorie = 3·968 B.Th.U.

One B.Th.U. = 0·252 Calorie.

One B.Th.U. = 778 ft. lb. = 107·6 kg. metres.

One Calorie = 427 kg. metres = 3087·3 ft. lb.

$$\frac{\text{B.Th.U. per lb.}}{1{\cdot}8} = \text{Cals. per kg.}$$

$$\frac{\text{Cals. per kg.}}{0{\cdot}556} = \text{B.Th.U. per lb.}$$

$$\frac{\text{B.Th.U. per cu. ft.}}{0{\cdot}1123} = \text{Cals. per cu. metre.}$$

$$\frac{\text{Cals. per cu. metre}}{8{\cdot}903} = \text{B.Th.U. per cu. ft.}$$

When 1 lb. of hydrogen is burnt to form water vapour at 212° F., 52,380 B.Th.U. are liberated.

If the water vapour is condensed to liquid at 212° F., a total of 63,100 B.Th.U. will be liberated by the combustion of 1 lb. of hydrogen.

Similarly 1 kg. of hydrogen burning to water vapour at 100° C. liberates 29,030 Calories, or, again, if the water vapour is condensed to liquid at 100° C., a total of 34,500 Calories will be liberated per kg. of hydrogen.

Carbon may be burnt to form either carbon monoxide (CO) or carbon dioxide (CO_2), and, further, carbon monoxide may be burnt to form carbon dioxide. Thus 1 lb. of carbon burning to carbon dioxide liberates 14,544 B.Th.U., or 1 kg. of carbon burning to carbon dioxide liberates 8080 Calories.

Again, 1 lb. of carbon burning to carbon monoxide liberates 4350 B.Th.U., and 1 kg. of carbon burning to carbon monoxide liberates 2430 Calories.

Also 1 lb. of carbon monoxide gas burning to carbon dioxide liberates 4383

TABLE I.

CHEMICAL REACTIONS OF ELEMENTS.

(By H. S. Buckley.)

Substance.	Molecular Formula.	Molecular Weight.	Lb. per cu. ft.	Cu. ft. per lb.	Grams per Litre.	Litres per Gram.	Required to burn one Unit. Weight. Air.	Weight. Oxygen.	Volume. Air.	Volume. Oxygen.	Chemical Reaction of Combustion.	Product of Combustion.	Heat Generated by Combustion of one Lb. B.Th.U.	Cu. ft. B.Th.U.	Kg. Calories.	Cu.Metre. Calories.
Carbon	C_2	24					11·594	2·667			$\frac{1}{2}C_2+O_2=CO_2$ 12+32=44 1 Vol.=1 Vol.	CO_2	14,544		8,080	
Carbon	C_2	24					5·79	1·334			$\frac{1}{2}C_2+\frac{1}{2}O_2=CO$ 12+16=28 $\frac{1}{2}$ Vol.=1 Vol.	CO	4,350		2,430	
Carbon Monoxide	CO	28	·07817	12·80	1·2515	·800	2·484	0·571	2·381	0·50	$CO+\frac{1}{2}O_2=CO_2$ 28+16=44 1 Vol.+$\frac{1}{2}$ Vol.=1 Vol.	CO_2	4,383	342	2,436	3,047
Hydrogen	H_2	2	·00559	178·83	·08961	11·16	34·785	8·00	2·39	0·50	$H_2+\frac{1}{2}O_2=H_2O$ 2+16=18 1 Vol.+$\frac{1}{2}$ Vol.=1 Vol.	H_2O Liquid	62,100	347	34,500	3,091
Hydrogen	H_2	2	·00559	178·83	·08961	11·16	34·785	8·00	2·39	0·50	$H_2+\frac{1}{2}O_2=H_2O$ 2+16=18 1 Vol.+$\frac{1}{2}$ Vol.=1 Vol.	H_2O Vapour	52,000	293	29,030	2,612
Sulphur	S_2	64					4·35	1·00			$\frac{1}{2}S_2+O_2=SO_2$ 32+32=64 1 Vol.=1 Vol.	SO_2	3,950		2,196	
Oxygen	O_2	32	·08926	11·203	1·4298	·699					Incombustible					
Nitrogen	N_2	28	·07845	12·763	1·2561	·796					Incombustible					
Carbon Dioxide	CO_2	44	·12344	8·147	1·967	·508					Incombustible					

B.Th.U. and 1 kg. liberates 2436 Calories under the same conditions. This and additional information is given in tabular form in Table 1.

TABLE Ia.

Percentage Saving of Coal Effected by Raising Efficiency of Plant.

Initial Efficiency %.	Final Efficiency obtained %.								
	45.	50.	55.	60.	65.	70.	75.	80.	85.
40	11·2	20	27·2	33·3	38·5	42·8	46·7	50·0	52·9
45	—	10	18·2	25·0	30·8	35·7	40·0	43·8	47·1
50	—	—	9·2	16·7	23·1	28·6	33·3	37·5	41·2
55	—	—	—	8·3	15·3	21·3	26·7	31·3	35·3
60	—	—	—	—	7·7	14·3	20·0	25·0	29·4
65	—	—	—	—	—	7·2	13·3	18·8	23·6
70	—	—	—	—	—	—	6·7	12·5	17·7
75	—	—	—	—	—	—	—	6·3	11·8
80	—	—	—	—	—	—	—	—	5·8

Steam and Gases.

The total heat present in steam depends on the pressure of the steam. In the case of the majority of furnace and combustion problems where steam is produced, it may be considered to exist as a true gas under a constant pressure at or about 760 mm. mercury, in which case the following values for its mean specific heat between 0° C. or 32° F. and a given temperature $t°$ may be taken :—

Per cu. metre up to 2000° C. = 0·34 + 0·00015t Calories.
Per kg. to up 2000° C. = 0·42 + 0·000185t Calories.
Per cu. ft. up to 3600° F. = 0·021 + 0·0000005t B.Th.U.
Per lb. up to 3600° F. = 0·42 + 0·000103t B.Th.U.

When the steam exists in its saturated state under its maximum tension, as in a steam boiler, the *total heat* may be obtained from steam tables 4, 5 and 6, given in the following pages, or by calculation, using the formula Q = 606·5 + 0·305t, where Q = total heat per kg. in Calories, and t = temperature in degrees centigrade corresponding to steam pressure.

In many cases when dealing with water vapour or steam at atmospheric pressure, it is convenient to consider the amount of heat required to convert water to its vapour at 0° C. (which amounts to 606·5 Calories per kg. or 1091 B.Th.U. per lb.) and afterwards treating the vapour as a true gas by any of the formulæ given above. This simplifies the calculation and does not introduce sensible errors.

The latent heat of vaporisation of water at 100° C. or 212° F. is 537 Calories per kg. or 970 B.Th.U. per lb.

The foregoing formulæ, with the saturated and superheated steam tables 4, 5 and 6, will enable any industrial problem in connection with water vapour to be solved with sufficient accuracy for practical purposes.

Reference may also be made to Tables 2 and 3, wherein the thermal capacities of gases, including water vapour, are given per kg. and per molecular volume respectively at various temperatures. Corresponding values at temperatures intermediate

to those given may be obtained by calculation, or by plotting on squared paper, the latter method being the quicker.

TABLE II.

Thermal Capacities of Gases.

Kilogram Calories per Kilo.

Temperature.	O_2.	N_2 and CO.	H_2.	H_2O.	CO_2.	CH_4.
0° C.	0	0	0	0	0	0
200	47·3	50	700	100	43·1	136·6
400	88·0	100	1400	203	91·0	303
600	134·0	154	2150	326	145	499
800	181·0	207	2900	461	208	726
1000	232·0	264	3700	609	277	982
1200	284·0	325	4550	770	354	1269
1400	334·0	383	5350	943	435	1584
1600	391·0	445	6250	1130	523	1931
1800	444·0	508	7100	1330	618	2307
2000	503·0	575	8050	1542	728	2712
2200	558·0	637	8950	1751	840	3148
2400	620·0	708	9900	1985	950	3614
2600	681·0	777	10900	2241	1070	4109
2800	735·0	850	11900	2520	1200	4365
3000	810·0	921	12950	2799	1355	5190

Note.—Kilogram Calorie or large calorie, usually written "Cal.," is the quantity of heat required to raise 1 kg. of water 1° Centigrade. The small calorie, usually written "cal.," is the quantity of heat required to raise 1 gram of water 1° Centigrade, in each case at a mean temperature of 15° Centigrade. 1 Cal. is therefore equal to 1000 cals., or 1 cal. is equal to $\frac{1}{1000}$ Cal.

TABLE III.

Thermal Capacities of Gases.

Kilogram Calories per Gram Molecule.

Temperature.	O_2, N_2, H_2 and CO.	H_2O.	CO_2.	CH_4.
0° C.	0	0	0	0
200	1·39	1·73	1·85	2·19
400	2·82	3·69	3·99	4·85
600	4·31	5·87	6·44	8·02
800	5·82	8·23	9·18	11·46
1000	7·43	10·98	12·22	15·77
1200	9·05	13·87	15·55	20·37
1400	10·73	17·00	19·18	25·44
1600	12·46	20·35	23·10	30·99
1800	14·21	23·86	27·21	36·86
2000	16·05	27·76	31·84	43·55
2200	17·91	31·82	36·65	50·54
2400	19·84	36·10	41·76	58·02
2600	21·81	40·62	47·16	66·04
2800	23·82	45·64	52·84	74·42
3000	25·89	50·64	58·86	83·84

Note.—The figures given above are of sufficient accuracy for general calculations. Resultants given by the three known methods of determining thermal capacities of gases, by the constant volume method, the constant pressure method, and by the explosion method, vary considerably.

TABLE IV.

Properties of Saturated Steam.

Absolute Pressure lb. per sq. in.	Temperature °F.	Water Heat from 32° F.	Latent Heat of Vaporisation.	Total Heat per lb. B.Th.U.	Volume Cu. Ft. per Lb.
0·5	79·7	48·8	1047	1096	641
1	108·8	69·8	1035	1105	333
2	126·1	94·2	1022	1116	173
3	141·5	109·6	1012	1122	118·4
4	153·0	121·0	1006	1126	90·4
5	162·3	130·3	1000	1130	73·3
6	170·1	138·1	996	1134	61·9
7	176·8	144·9	991	1136	53·6
8	182·9	150·9	988	1139	47·3
9	188·3	156·4	985	1141	42·4
10	193·2	161·3	981	1143	38·4
11	197·7	165·9	979	1145	35·1
12	202·0	170·1	976	1146	32·4
13	205·9	174·1	974	1148	30·1
14	209·6	177·8	971	1149	28·0
14·72	212·0	180·2	970	1150	26·7
15	213·0	181·3	969	1150	26·3
16	216·3	184·6	967	1152	24·7
17	219·4	187·8	965	1153	23·4
18	222·4	190·8	963	1154	22·2
19	225·2	193·7	961	1155	21·1
20	228·0	196·4	959	1156	20·1
21	230·6	199·1	957	1157	19·19
22	233·1	201·6	956	1158	18·37
23	235·5	204·1	954	1159	17·62
24	237·8	206·4	953	1159	16·92
25	240·1	208·7	951	1160	16·29
26	242·3	210·9	950	1161	15·70
27	244·4	213·0	949	1162	15·17
28	246·4	215·1	947	1162	14·67
29	248·4	217·2	946	1163	14·19
30	250·3	219·1	944	1164	13·74
35	259·3	228	938	1166	11·88
40	267·3	236	933	1169	10·49
45	274·5	244	927	1171	9·39
50	281·0	250	923	1173	8·51
55	287·1	257	918	1175	7·78
60	292·7	262	914	1177	7·17
65	298·0	268	910	1178	6·65
70	303·0	273	907	1180	6·20
75	307·6	278	903	1181	5·81
80	312·1	282	900	1182	5·47
85	316·3	287	897	1183	5·16
90	320·3	291	894	1184	4·89
95	324·2	295	890	1185	4·64
100	327·9	299	888	1186	4·43
105	331·4	302	885	1187	4·23
110	334·8	306	882	1188	4·05
115	338·1	309	880	1189	3·88
120	341·3	312	877	1189	3·72
125	344·4	316	874	1190	3·58
130	374·4	319	872	1191	3·45
135	350·3	322	870	1191	3·33
140	353·1	324	867	1192	3·22
145	355·8	327	865	1193	3·12

TABLE IV (*continued*).

Properties of Saturated Steam.

Absolute Pressure lb. per sq. in.	Temperature °F.	Water Heat from 32° F.	Latent Heat of Vaporisation.	Total Heat per lb. B.Th.U.	Volume Cu. Ft. per. Lb.
150	358·5	330	863	1193	3·01
155	361·1	333	861	1194	2·92
160	363·6	335	859	1194	2·83
165	366·1	338	857	1195	2·75
170	368·5	340	855	1195	2·67
175	370·9	343	853	1196	2·60
180	373·2	345	851	1196	2·53
185	375·4	348	849	1197	2·48
190	377·6	350	847	1197	2·41
195	379·8	352	845	1197	2·35
200	381·9	354	844	1198	2·29
205	384	356	842	1198	2·24
210	386	359	840	1199	2·18
215	388	361	838	1199	2·14
220	390	363	837	1199	2·09
225	392	365	835	1200	2·04
230	394	367	833	1200	2·00
235	396	369	832	1201	1·96
240	398	371	830	1201	1·92
245	399	372	829	1201	1·88
250	401	374	827	1201	1·85
265	406	380	822	1202	1·74
315	422	396	808	1204	1·47
365	435	409	797	1206	1·27
415	447	422	784	1207	1·115

TABLE V.

Table of Mean Specific Heats of Superheated Steam from Saturation Temperature.

Pressure Lb. per sq. in. Absolute.	Superheat, °F.						
	50.	100.	150.	200.	250.	300.	350.
10	·456	·456	·457	·458	·458	·459	·460
20	·468	·467	·466	·466	·466	·467	·468
30	·479	·477	·475	·474	·474	·475	·475
40	·490	·486	·484	·482	·482	·482	·482
50	·501	·495	·492	·490	·488	·488	·487
60	·512	·504	·500	·496	·494	·493	·492
70	·522	·513	·507	·502	·499	·498	·496
80	·532	·521	·513	·507	·504	·502	·500
90	·541	·529	·519	·512	·508	·506	·504
100	·549	·536	·525	·517	·512	·509	·507
120	·566	·549	·534	·525	·519	·515	·514
140	·587	·560	·543	·533	·526	·521	·520
160	·602	·570	·551	·538	·531	·526	·524
180	·620	·581	·559	·543	·535	·531	·528
200	·632	·591	·565	·549	·540	·536	·533

TABLE VI.

Table of Heat Required to Superheat 1 lb. of Steam.

Pressure Lb. per sq. in. Absolute.	Superheat, °F.						
	50.	100.	150.	200.	250.	300.	350.
10	22·8	45·6	67·5	91·6	114·5	137·7	161·0
20	23·4	46·7	69·9	93·2	116·5	140·1	163·7
30	23·9	47·7	71·2	94·8	118·5	142·5	166·2
40	24·5	48·6	72·5	96·4	120·5	144·6	168·6
50	25·0	49·5	73·8	98·0	122·0	146·4	170·4
60	25·6	50·4	75·0	99·2	123·5	147·9	172·1
70	26·1	51·3	76·0	100·4	124·7	149·4	173·6
80	26·6	52·1	77·0	101·4	126·0	150·6	175·0
90	27·0	52·9	77·9	102·4	127·0	151·8	176·3
100	27·4	53·6	78·8	103·4	128·0	152·7	177·4
120	28·3	54·9	80·1	105·0	129·7	154·5	179·8
140	29·3	56·0	81·4	106·6	131·5	156·3	182·0
160	30·1	57·0	82·6	107·6	132·7	157·8	183·4
180	31·0	58·1	83·8	108·6	133·7	159·3	184·7
200	31·6	59·1	84·9	109·8	135·0	160·8	186·5

TABLE VII.

Specific Heats of Gases.

Substance.	Centigrade Scale.			Fahrenheit Scale.		
	Temperature Range.	Cal. per Kilo.	Cal. per Cu. Metre.	Temperature Range.	B.Th.U. per Lb.	B.Th.U. per cu. ft.
Hydrogen . .	0°–2000°	3·370 + 0·0003 t.	0·303 + ·000027 t.	32°–3600°	3·370 + 0·00017 t.	0·0189 + ·0000009 t.
Oxygen . .	0°–2000°	0·2104 + ·0000187 t.	0·303 + ·000027 t.	32°–3600°	0·2104 + ·0000104 t.	0·0189 + ·0000009 t.
Nitrogen . .	0°–2000°	0·2405 + ·0000214 t.	0·303 + ·000027 t.	32°–3600°	0·2405 + ·0000119 t.	0·0189 + ·0000009 t.
Carbon monoxide .	0°–2000°	0·2405 + ·0000214 t.	0·303 + ·000027 t.	32°–3600°	0·2405 + ·0000119 t.	0·0189 + ·0000009 t.
Carbon dioxide .	0°–2000°	0·19 + ·00011 t.	0·370 + ·00022 t.	32°–3600°	0·19 + ·00006 t.	0·023 + ·000008 t.
Water vapour .	0°–2000°	0·42 + ·000185 t.	0·340 + ·00015 t.	32°–3600°	0·42 + ·000103 t.	0·021+ ·000005 t.

Air Mixtures and Water Vapour.

TABLE VIII.

WEIGHT AND VOLUME OF AIR, VAPOUR AND SATURATED MIXTURES OF AIR AND VAPOUR AND DIFFERENT TEMPERATURES UNDER ATMOSPHERIC PRESSURE OF 29·921 IN. OF MERCURY.

Temperature, °F.	Volume of dry air at various Temperatures. The Volume at 32° F = 1.	Weight of Cu. Ft. of the Mixture of Air and Vapour.		
		Weight of the Air. lb.	Weight of the Vapour. lb.	Total Weight of Mixture. lb.
0	0·935	0·086226	0·000077	0·086303
12	0·960	0·083943	0·000130	0·084073
22	0·980	0·082083	0·000198	0·082281
32	1·000	0·080239	0·000300	0·080539
42	1·020	0·078411	0·000435	0·078846
52	1·041	0·076563	0·000621	0·077184
62	1·061	0·074667	0·000874	0·075541
72	1·082	0·072690	0·001213	0·073903
82	1·102	0·070595	0·001661	0·072256
92	1·122	0·068331	0·002247	0·070578
102	1·143	0·065890	0·002999	0·068849
112	1·163	0·063085	0·003962	0·067047
122	1·184	0·059970	0·005175	0·065145
132	1·204	0·056425	0·006689	0·063114
142	1·224	0·052363	0·008462	0·060825
152	1·245	0·047686	0·010854	0·058540
162	1·265	0·042293	0·013636	0·055929
172	1·285	0·036055	0·016987	0·053042
182	1·306	0·028845	0·021000	0·049845
192	1·326	0·020545	0·025746	0·046291
202	1·347	0·010982	0·031354	0·041336
212	1·367	0·000000	0·037922	0·037922

Heat Contained in Metals at Various Temperatures.

TABLE IX.

Heat Content of Pure Iron at Various Temperatures.

	Temperature.		Total Heat Content.	
	°F.	°C.	B.Th.U. per Lb.	Cals. per Kilo.
	482	250	54·9	30·5
	572	300	67·9	37·7
	662	350	81·0	45·0
	752	400	94·0	52·2
	842	450	108·5	60·3
	932	500	122·9	68·3
	1022	550	138·1	76·7
	1112	600	153·0	85·0
	1202	650	171·2	95·1
	1292	700	201·3	112·0
	1382	750	226	125·5
	1472	800	244	135·5
	1562	850	260	144·5
	1652	900	275	153
	1742	950	289	160
	1832	1000	302	168
	1922	1050	316	175
	2012	1100	329	183
	2102	1150	345	192
	2192	1200	360	200
	2282	1250	375	209
	2372	1300	389	216
	2482	1350	404	225
	2552	1400	420	233
	2642	1450	435	242
	2732	1500	450	250
	2822	1550	465	259
Solid	2912	1600	480	267
Liquid	2912	1600	605	336
	3002	1650	623	347
	3092	1700	641	356
	3182	1750	659	366
	3272	1800	677	376
	3362	1850	695	386
	3452	1900	713	396
	3542	1950	730	406
	3632	2000	749	416

TABLE X.

Heat Required to Melt Metals.

Metal.	Melting Point.		Heat in Solid Metal at M.P.		Latent Heat of Fusion.		Heat in Liquid Metal at M.P.	
	°C.	°F.	Cals. per kilo.	B.Th.U. per lb.	Cals. per kilo.	B.Th.U. per lb.	Cals. per kilo.	B.Th.U. per lb.
Casium . .	29°	82°	1·4	2·52	4·8	8·64	6·2	11·16
Potassium . .	60	140	11·4	20·55	13·6	24·45	2·5	45
Sodium . .	98	208	30·6	55·15	27·2	49	57·8	104·15
Selenium . .	217	423	18	32·4	4	7·2	22	39·6
Tin . . .	232	450	14·34	25·85	13·82	24·9	28·16	50·75
Bismuth . .	269	516	9·0	16·2	12	21·6	21	37·8
Cadmium . .	321	610	18·8	34	13	23·4	31·8	57·4
Lead . . .	327	622	11·6	20·9	6	10·8	17·6	31·7
Zinc . . .	419	787	45·2	81·4	22·6	40·7	67·8	122·1
Tellurium . .	455	852	27·3	49·2	19	34·2	46·3	83·4
Cerium . .	623	1153	27·9	50·3	13·4	24·15	41·3	74·45
Antimony . .	630	1166	34	61·25	40·3	72·6	74·3	133·85
Magnesium .	650	1202	212	382	70	126	282	508
Aluminium .	657	1214	167·4	301·5	90·9	163·5	258·3	465
Calcium . .	800	1472	136·3	245	56·3	101·3	192·6	346·3
Barium . .	850	1562	42·5	76·5	17	30·6	59·5	107·1
Silver . .	962	1764	64·8	116·6	24·35	43·8	89·15	160·4
Gold . . .	1064	1947	34·63	62·4	16·3	29·3	50·93	91·7
Copper . .	1083	1982	118·7	213·7	43·3	78·1	162	291·8
Manganese . .	1207	2204	281	506	43	77·4	324	583·4
Silicon . .	1430	2607	386	695	108	194·5	494	889·5
Nickel . .	1450	2643	221	398	68	122·5	289	520·5
Chronium . .	1489	2712	352	634	71	128	423	762
Cobalt . .	1490	2714	259	466	68	122·5	327	588·5
Iron (pure) .	1535	2795	256	461·5	66	188·5	322	580
Palladium . .	1459	2820	110	198	36	65	146	263
Thorium . .	1690	3074	68·5	123	180	324	248·5	447
Vanadium . .	1710	3110	267	480	82	147·5	349	627·5
Platinum . .	1755	3191	75·2	135·3	27·2	49	102·4	184·3
Titanium . .	1795	3264	187	337	90	162	277	499
Ruthenium .	1950	3542	155	279	46	82·8	201	361·8
Rhodium . .	1970	3578	152	273·5	53	95·5	205	369
Uranium . .	2000	3632	83	149·5	20	36	103	185·5
Osmium . .	2200	3992	96	173	36	65	132	238
Zirconium . .	2350	4252	155	280	61	110	216	390
Iridium . .	2360	4280	108	194·5	28	50·5	136	245
Molybdenum .	2500	4532	289	520	61	110	350	630
Tantalum . .	2900	5252	233	420	37	66·5	270	486·5
Tungsten . .	3350	6062	234	422	40	72	274	494

A LIST OF SOME COMPLETE PULVERISED COAL INSTALLATIONS AND SELF-CONTAINED UNITS IN VARIOUS COUNTRIES.

(JULY 1921.)

As compiled by "Chaleur et Industrie."

North and South America.

OPEN HEARTH STEEL MELTING FURNACES.

Name of Works.	Situation.
American Rolling Mills Co.	Middletown, Ohio.
American Steel Foundries	Sharon, Pa.
American Steel & Wire Co.	Donora, Pa.
Armstrong-Whitworth Co.	Montreal, Quebec.
Atlantic Steel Co.	Atlanta, Ga.
Carnegie Steel Co.	Clairton, Pa.
,, ,,	Homestead, Pa.
,, ,,	Sharon, Co.
Eastern Steel Co.	Pottsville, Pa.
Follansbee Bros.	Follansbee, W. Va.
National Malleable Cast Co.	Cleveland, Ohio.
,, ,, ,,	Melrose Park, Ill.
,, ,, ,,	Sharon, Pa.
Sharon Steel Hoop Co.	Sharon, Pa.

PUDDLING FURNACES.

Bethlehem Steel Co.	Lebanon, Pa.
Burdon Iron Co.	Troy, N.Y.
Fort Wayne Rolling Mill Co.	Fort Wayne, Ind.
London Rolling Mills	London, Ont., Canada.
Knoxville Iron Co.	Knoxville, Tenn.
Milton Manufacturing Co.	Milton, Pa.
Scranton Bolt & Nut Co.	Scranton, Pa.
St. Louis Screw Co.	St. Louis, Mo.
Union Rolling Mills	Cleveland, Ohio.

CONTINUOUS REHEATING FURNACES FOR BLOOMS AND BILLETS.

Allegheny Steel Co.	Brackenridge, Pa.
American Steel & Wire Co.	Cleveland, Ohio.
Bethlehem Steel Co.	Steelton, Pa.
Carnegie Steel Co.	Clairton, Pa.
Dilworth-Porter Co., Inc.	Pittsburgh, Pa.
Inland Steel Co.	Indiana Harbour, Ill.
Midvale Steel Co.	Philadelphia, Pa.
National Pressed Steel Co.	Massillon, Ohio.
Oliver Steel & Iron Co.	Pittsburgh, Pa.
Tennessee Coal & Iron Co.	Birmingham, Ala.
Union Rolling Mills Co.	Cleveland, Ohio.
Upson Nut Co.	Cleveland, Ohio.

Forge Furnaces.

Name of Works.	Situation.
American Chain Works	York, Pa.
American Locomotive Co.	Schenectady, N.Y.
American Spiral Pipe Works	Chicago, Ill.
Baldwin Locomotive Works	Philadelphia, Pa.
Bethlehem Steel Co.	Lebanon, Pa.
Burdon Iron Co.	Troy, N.Y.
A. M. Byers Co.	Pittsburg, Pa.
Calumet Steel Co.	Chicago Heights, Ill.
Carnegie Steel Co.	Sharon, Pa.
" "	Youngstown, Ohio.
Dilworth-Porter Co., Inc.	Pittsburg, Pa.
E. Dulieux	New York City.
Eastern Steel Co.	Pottsville, Pa.
Falcon Steel Co.	Niles, Ohio.
Follansbee Brothers	Follansbee, W. Va.
Fort Wayne Rolling Mill Co.	Fort Wayne, Ind.
Hubbard & Co.	Pittsburg, Pa.
Inland Steel Co.	Chicago Heights, Ill.
" "	Indiana Harbor, Ill.
A. Kelly Manufacturing Co.	Charleston.
Knoxville Iron Co.	Knoxville, Tenn.
Lima Locomotive Works, Inc.	Lima, Ohio.
Mansfield Sheet & Tinplate Co.	Mansfield, Ohio.
Middletown Car Co.	Middletown, Ohio.
Midvale Steel Co.	Philadelphia, Pa.
Milton Manufacturing Co.	Milton, Pa.
Newport Rolling Mill Co.	Newport, Ky.
Pittsburg Forge & Iron Co.	Pittsburg, Pa.
Oliver Iron & Steel Co.	Pittsburg, Pa.
Scranton Bolt & Nut Co.	Scranton, Pa.
Scranton Forging Co.	Scranton, Pa.
Standard Forgings Co.	Indiana Harbor, Ill.
Sizer Forge Co.	Buffalo, N.Y.
Standard Steel Works	Burnham, Pa.
St. Louis Screw Co.	St. Louis, Mo.
U.S. Horseshoe Co.	Erie, Pa.
" "	Manitoba, Canada.
Verona Tool Co.	Pittsburg, Pa.
Warwood Tool Co.	Warwood, W. Va.
Wood, Allan Iron & Steel Co.	Conshohocken, Pa.

Malleable Iron Furnaces and Steel Rolling Mills.

American Malleable Co.	Owasso, Mich.
American Radiator Co.	Buffalo, N.Y.
Benton Harbour Malleable Co.	Benton Harbour, Mich.
Erie Malleable Iron Co.	Erie, Pa.
Falcon Steel Co.	Niles, Ohio.
Follansbee Brothers	Follansbee, W. Va.
General Electric Co.	Erie, Pa.
Globe Seamless Steel Tubes Co.	Milwaukee, Wis.
International Harvester Co.	Chicago, Ill. (Deering).
" " "	" (McCormick).
" " "	Hamilton, Ont., Canada.
Kalamazoo Malleable Iron Co.	Kalamazoo, Mich.
Lima Locomotive Works, Inc.	Lima, Ohio.
National Malleable Cast. Co.	Cleveland, Ohio.
" " "	Sharon, Pa.
Newport Rolling Mill Co.	Newport, Ky.
Pittsburg Malleable Iron Co.	Pittsburg, Pa.
Pressed Steel Car Co.	" "
T. H. Symington Co.	Rochester, N.Y.

Sheet and Tin Plate Mills.

Name of Works.	Situation.
American Rolling Mills Co.	Middletown, Ohio.
Follansbee Bros.	Follansbee, W. Va.
Liberty Steel Co.	Warren, Ohio.
Mansfield Sheet & Tinplate Co.	McKeesport, Pa.
Newport Rolling Mill Co.	Newport, Ky.
Otis Steel Co.	Cleveland, Ohio.
Philipps Sheet & Tinplate Co.	Clarksburg, W. Va.
Standard Tin Plate Co.	Canonsburg, Pa.
Trumbull Steel Co.	Warren, Ohio.
Weirton Steel Co.	Clarksburg, W. Va.

Various Furnaces and Galvanising Kettles.

A. M. Byers Co.	Pittsburg, Pa.
Canton Steel Foundry Co.	Canton, Ohio.
Chicago Rly. Equipment Co.	Franklin, Ohio.
Follansbee Bros.	Follansbee, W. Va.
De Forest Sheet & Tin Plate Co.	Niles, Ohio.
London Rolling Mill Co.	London, Ontario, Canada.
Newport Rolling Mill Co.	Newport, Ky.
Otis Steel Co.	Cleveland, Ohio.
Pressed Steel Car Co.	McKees Rocks, Pa.
United Long, and Dry Co.	Canton, Ohio.

Soaking Pits.

Atlantic Steel Co.	Atlanta, Ga.
Follansbee Bros.	Follansbee, W. Va.

Nodulising Furnaces.

Algoma Steel Corporation	Sault Ste-Marie, Ont.
Carolina Ore Co.	Winston-Salem, N.C.
Central Iron & Coal Co.	Hold, Ala.
Charleston Ore Co.	Charleston, S.C.
Chicago Railway Equipment Co.	Marion, Ohio.
,, ,, ,, ,,	Grande Rapide, Mich.
Eastern Nodulising Works	Newark, N.J.
General Chemical Co.	
International Nickel Co.	Copper Cliff, Ont.
Lackawanna Steel Co.	Buffalo, N.Y.
Michigan Malleable Iron Co.	Detroit, Mich.
Mississippi Valley Iron Co.	Waukon, Iowa.
Muncie Malleable Foundry Co.	Muncie, Ind.
Northern Iron Works	Standish, N.Y.
Pennsylvania Salt Manufacturing Co.	Natrona, Pa.
,, ,, ,,	Philadelphia, Pa.
Princess Furnace Co.	Glen Wilton, Va.
Spanish American Iron Co.	Cuba.
Timken Detroit Axle Co.	Canton, Ohio.
Virginia Coal & Coke Co.	Middlesboro, Ky.

Copper Smelting and Melting Furnaces.

Name of Works.	Situation.
American Smelting & Refining Co.	Garfield, Utah.
” ” ”	Hayden, Ariz.
” ” ”	Maurer, N.J.
” ” ”	Taceoma, Wash.
” ” ”	Mexico.
Anaconda Copper Mining Co.	Anaconda, Mont.
” ” ”	Great Falls, Mont.
Brader Copper Co.	Valparaiso, Chili.
Canadian Copper Co.	Copper Cliff, Ont.
Cerro de Pasco Copper Co.	N.Y.
Corporation Minera de Famatina (3)	Sud Amerique.
Lake Superior Smelting Co.	Dollar Bay, Mich.
Michigan Smelting Co.	Houghton, Mich.
Nevada Cons. Copper Co.	McGill, New.
Nichols Copper Co.	Long Island, N.Y.
Perth Amboy Plt. of American Smelting Refining Co.	Maurer, N.J.
River Smelting & Ref. Co.	Florence, Colo.
Tacona Smelter	Tacona, Wash.
United Verde Copper Co.	Clarkdale, Ariz.
United Verde Ex. Mining Co.	Verdi, Ariz.
United States Smelting Refining Co.	Salt Lake City, Utah.

Zinc Industry and Smelting Furnaces.

Bartelsville Zinc Co.	Collinsville, Okla.
Edgar Zinc Co.	Cherryvale, Kans.
River Smelting & Ref. Co.	Florence, Colo.

Furnaces for Gold and Silver Refining.

Granite Gold Mining Co.	Victor, Colo.
River Smelting & Ref. Co.	Florence, Colo.

Heating, Calcining and Burning Furnaces in the Chemical and Various Industries.

Air Nitrates Co.	Sheffield, Ala.
Allan Wood Iron & Steel Co.	Conshohocken, Pa.
Alpha Portland Cement Co.	Alsen, N.Y.
American Bauxite Co.	Bauxite, Ark.
American Chem. & Min. Co.	Atlanta, Ga.
American Potash Co.	Portland, Ga.
Armour Fertiliser Works	Bartow, Fla.
Atlantic Potash Co.	Stockertown, Pa.
Bare Paper Co. (Lime Sludge)	Roa Ring Springs, Pa.
Bunker Hill Sullivan Mining & Concentration Co.	Kellog, Idaho.
Campbell Stone Co.	Afton, Mich.
Clinchfield Products Corp.	Johnson City, Tenn.
Coplay Portland Cement Manufacturing Co.	Coplay, Pa.
Dolomite Products Co.	Maple Grove, Ohio.
Florence Mining & Milling Co.	Marysville, Utah.
Harbison-Walker Refractories Co.	Chester, Pa.
Heppenstall Knife & Forge Co.	Pittsburg, Pa.
Industrial Lime Stone Co.	Nazareth, Pa.

Name of Works.	Situation.
International Agr. Corp.	Lockland, Ohio.
,, ,,	Norfolk, Va.
Kennedy Refractories Co.	Bainbridge, Pa.
Lackawanna Steel Co.	Buffalo, N.Y.
Liberty Potash Co.	Green River, Wy.
Manitoba Gypsum Co.	Winnipeg, Man.
Mineral Products Co.	Marysville, Utah.
National Carbon Co.	Niagara Falls, N.Y.
Niagara Gypsum Co.	Oakfield, N.Y.
Northwest Magnesite Co.	Chewellah, Wash.
Plymouth Gypsum Co.	Fort Dodge, Iowa.
Security Cement & Lime Co.	Hagerstown, Md.
Solvay Process Co.	Syracuse, N.Y.
Tennessee Coal, Iron & Railroad Co.	Birmingham, Ala.
Transue Williams & Co.	Alliance, Ohio.
Union Carbide Co.	Niagara Falls, N.Y.
,, ,,	Sault Ste. Marie, Mich.
,, ,,	Welland, Ont.

STATIONARY STEAM BOILERS.

Name of Works.	Situation.	Numbers and Type of Boilers (heating surface in M²).	Date of Installation.
American Locomotive Co.	Schenectady, N.Y.	1 Franklin 280 m².	1914.
Anaconda Copper Mining Co.	Anaconda, Mont.		
Armstrong-Whitworth Co.	Montreal, Quebec.		
Central Rly. of Brazil	Barro do Pirahy, Brazil, S.A.		
Choctaw Portland Cement Co.	Hartshorne, Okla.		
Hudson Coal Co.	Olyphant, Pa.	1 Stirling 463 m².	
Lackawanna Coal Co.	Lykens, Pa.		
Pacific Coast Coal Co.	Renton, Wash.		
Missouri Kansas and Texas Railway	Parsons, Kan.	8 Parsons 225 m².	1916.
Sizer Forge Co.	Buffalo, N.Y.	5 Vertical Rust 225 m².	1917.
Ash Grove Lime & Cement Co.	Chanute, Kansas.	1 Heine 340 m².	1918.
United Verde Extension Mining Co.	Jerome, Arizona, U.S.	2 Stirling 400 m².	1918.
Armstrong-Whitworth Co.	Montreal, Quebec.	3 Boilers.	
Chicago Rly. Equipment Co.	Marion, Ohio.	1 Boiler.	
,, ,, ,,	Franklin, Ohio.	3 Boilers.	
,, ,, ,,	Grand Rapids, Mich.	1 Boiler.	
Hennequin & Co.	Minneapolis & Summit Hotel.		
,, ,,	Minneapolis&Phœnix Bld.		
Garfield Smelting Co.	Garfield, Utah.	2 Stirling 240 m².	1918.
Milwaukee Electric Rly. & Light Co.	Milwaukee, Wis.	8 Edgemore 1215 m².	1921.
Puget Sound Traction, Light & Power Co.	Seattle, Wash.	B. & W. 4 de 260 m². 2 de 540 m². 3 de 360 m². 1 de 450 m².	1918.

STATIONARY STEAM BOILERS (*continued.*)

Name of Works.	Situation.	Numbers and Type of Boilers (heating Surface in M²).	Date of Installation.
L. S. Smith Bldg.	Seattle, Wash.	B. & W. 1 de 240 m². 1 de 180 m².	
Pacific Coast.	Seattle, Wash.	30 Boilers 100 à 220 m².	1918.
Lytle Coal Co.	Lytle, Pa.	6 B. & W. 310 m².	1919.
British Columbia Sugar Co.	Vancouver, B.C.	15 Boilers making in all 3240 m².	1919.
Milwaukee Electric Rly. & Light Co.	Milwaukee, Wis.	5 Edgemore 438 m².	1918.
Allegheny Steel Co.	Brackenridgeburg.	2 Wickes 300 m².	1919.
Inland Steel Co.	Chicago Heights, Ill.	1 Heine 225 m².	1919.
Susquehanna Collieries Co.	Lykens, Pa.	1 B. & W. 225 m².	1918.
” ” ”	Lykens, Pa.	6 Edgemore 360 m². 6 B. & W.	1921.
Morris & Co.	Oklahoma.	7 Edgemore 280 à 465 m².	1919.
Garfield Smelting Co.	Garfield, Utah.	6 Stirling 340 m².	1919.
Lima Locomotive Works.	Lima, Ohio.	1 Heine 530 m². 6 Wickes 400 m².	1919.
Armstrong-Whitworth Co.	Montreal, Canada.	3 Goldie McGullough 450 m².	1918.
Nevada Consolidated.	McGille, Nevada.	2 Boilers.	1918.
Bethlehem Steel Co.	Lebanon, Pa.	4 B. & W. 450 m².	1920.
Falcon Steel Co.	Niles, Ohio.	2 Badenhausen 195 m².	1920.
Knoxville Iron Co.	Knoxville, Tenn.	Stirling 2–500 m². 2–250 m².	1921.
Newton Steel Co.		2 B. & W.	
American Chain Co.		2 Stirling 235 m².	1920.
		2 Boilers.	1920.
Allentown Portland Cement Co.	Allentown, Pa.	5 Rust 360 m².	1920.
Southern Anthracite Co.		1 B. & W. 225 m².	1920.
Cayuga Operating Co.	Portland Point, N.Y.	1 B. & W. 270 m².	1920.
Ford Motor Co.	River Rouge, Mich.	4 Ladd 2380 m².	1920.
Kelly Axe Mfg. Co.	Charleston, W.V.	4 Boilers 675 m².	1920.
Chicago Rly. Equipment Co.	Franklin, Pa.	3 Boilers 270 m². 2–320 m². 1–360 m².	1920.
Philadelphia Rapid Transit Co.	Mt. Vernon, Pa. near Philadelphia.	10 B. & W. 350 m².	1920.
W. B. Nillein.	Milwaukee.	4 Wickes 465 m².	1920.
B. C. Sugar Refinery.	Vancouver, B.C.	4 Stirling, Badenhausen, 225 à 450 m².	1920.
American Chain Co.	York, Pa.	1 B. & W. 280 m².	1921.
Trumbull Steel Co.	Warren, Ohio.	2 Stirling 375 m².	1921.
Garfield Smelting Co.	Garfield, Utah.	5 Stirling 1–560 m². 4–345 m².	

COMPLETE PULVERISED COAL INSTALLATIONS AND SELF-CONTAINED UNIT EQUIPMENTS IN EUROPE.

France.

Fours (Furnaces).

Usines.	Situation.	Appareils.	Type d'Installation.
Citroen.	Paris.	3 ateliers de fours à réchauffer et chaudière.	Centrale de 5 Tonnes heure.
Vermot, Valère Mabille et R. Pelgrines.	Douzies (Nord).	16 fours.	Centrale Transport par air comprimé et ligne de circulation.
Jacob Holtzer.	St. Etienne.	Fours à réchauffer.	Centrale.
Arsenal de Roanne.	Roanne.		Centrale.
Lemoine.	St. Dizier.		Centrale Transport.
Progil.	Lyon.	Fours et chaudières.	
Bouchayer et Viallet.	Grenoble.	Fours et chaudières.	Centrale de 3 Tonnes heure.
Boulonneries de Bogny-Braux.	Ris-Orangis.	5 fours à souder.	
Aciéries de Sambre-et-Meuse.	Jeumont.	3 fours à recuire.	Centrale 500 heure.
Déflassieux.	Rive-de-Gier.	4 fours à réchauffer.	Turbo-pulvérisateur.
Sté. Métallurgique de Montbard-Aulnoye.	Aulnoye.	2 fours à réchauffer.	
Sté. Aciéries de St. Etienne.	St. Etienne.	3 fours à réchauffer.	
Claudinon et Cie.		2 fours à réchauffer.	
Aciéries de la Marine et d'Homecourt.	St. Chammond.	9 fours de forge.	
Sté. du Matériel Roulant.	Fourchambault.	6 fours de forge.	
J. Renault.	Billancourt.	2 fours de forge.	
J. J. Carnaud.	Basse-Indre.	3 fours de tôle.	
Arsenal de Tarbes.	Tarbes.	1 four à recuire.	
Schneider et Cie.	Le Creusot.	4 fours poussants.	
De Dietrich et Cie.	Niederbrom.	1 four à souder.	
Aciéries de St. Etienne.	St. Etienne.	1 four poussant.	Pulvéro-brûleur.
Sté. Métallurgique de la Bonneville.	La Bonneville (Eure).	1 four.	"
Cie. Française Aloxite.	Sarrancolin (H. Pyr).	1 four.	"
Aciéries de Sambre-et-Meuse.		3 fours à recuire les moulages d'acier.	
Hauts fourneaux forges et Aciéries de Pompey.	Pompey (M. et-M.).	Fours "pitts."	
Forges et Estampages de Suresnes.	Suresnes.	1 four.	
Usines Navarre.	Evreux.	1 four à réchauffer avec inversion.	
Vairet Baudot.	Ciry-le-Noble (S. et-Loire).	2 fours céramiques.	Turbo-pulvérisateur.
Forges d'Eurville.		1 four à réchauffer.	

Fours (*Furnaces*).

Usines.	Situation.	Appareils.	Type d'Installation.
Bloch et Cie.	Aubervilliers.	1 four à souder.	
Société Française Babcock et Wilcox.	La Courneuve.	11 fours divers.	
E. Dervaux (boulonnerie et ferronnerie).	Vieux-Condé.	1 four à réchauffer.	
Ferrure et Estampage du N.E.	Mézières.	1 four d'estampage.	
Sté. Métallurgique de Corcy.	Corcy.	1 four.	
Marchal et Cie.	Pantin.	1 four.	
Aciéries d'Imphy.	Imphy.	1 four à réchauffer.	
Glachant.	Pantin.	1 four de forge.	
Hts. Fourneaux, forges aciéries du Saut du Tarn.		1 four à réchauffer.	
De Wendel et Cie.	Hayange.	1 four à réchauffer.	
Sté. Escaut et Meuse.		2 fours à réchauffer.	
Robert et Cie.	St. Dizier.	1 four à souder.	
Sté. Forges de Strasbourg.		1 four poussant.	
Forges d'Onzion.	Onzion.	3 fours à souder.	
Forges de Cambeplaine.		1 four.	
Aciéries P. Girod.	Ugine.	2 fours à réchauffer.	
Usine du Clos-Mortier.	St. Dizier.	1 four.	
Etablissement Kuhlmann.		3 fours.	
Experton Revollier.	Renage.	1 four de forge.	Pulvéro-brûleur.
Fonderie forges et Aciéries de St. Etienne.	St. Etienne.	2 fours à réchauffer.	
Aciéries de Corumercy.	Corumercy.	3 fours à réchauffer.	Turbo-pulvérisateur.
Sté. Métallurgique d'Arriège.	Pamiero.	1 four poussant.	,,
Etablissement Caill.	Dervaine.	1 four de forge.	,,
Etablissement Arbel.	Couzon.	1 four à réchauffer.	,,
Afort et Cie.	Monon.	1 four poussant.	,,
Cie des Fives Lille.	Fives Lille.	1 four à réchauffer.	,,
Forges et Chantiers de la Méditerranée.	Le Havre.	1 four de forge.	,,
M. Capitaine Zerny.	Revin.	1 four.	,,
Aciéries de Nicolas.		3 fours à réchauffer.	,,
Etablissement Jacob Holtzer.		1 four à réchauffer.	,,
Sté. Métallurgique Electrique.		1 four à réchauffer.	,,
Silvio Giro.	Massaic (Cantal).	1 four.	Pulvéro-brûleur.
Aciéries et Forges de St. Louis.	Marseille.	1 four poussant.	,,

Chaudières (*Boilers*).

Usines.	Situation.	Appareils.	Type d'Installation.
Citroen.	Paris.	1 chaudière Niclausse.	(Déjà citée, marche depuis 1919.)
Commentry-Fourchambault.	Fourchambault.	1 chaudière de Nayer.	Centrale (marche depuis 4 à 5 mois).
Bouchayer et Viallet.	Grenoble.	chaudières.	Centrale de 3 tonnes-heure (marche depuis Decembre 1920).
Mines de Houille de Blanzy.	Montceau-les-Mines.	1 chaudière.	Centrale de 2 tonnes-heure.
Mines de Houille de Blanzy.	Montceau-les-Mines.	1 chaudière.	Centrale de 5 tonnes-heure.
Vermot, Valère, Mabille et R. Pelgrines.	Douzies (Nord).	9 chaudières.	Centrale.
Progil.	Lyon.	Plusieurs chaudières.	(Déjà citée.)
Boulonneries-de Bogny-Braux.	Ris-Orangis.	5 chaudières semi-tubulaires sch = 125^2. 2 chaudières semi-tubulaires sch = 250 m^2. 2 chaudières B.W. sch = 250 m^2.	(Déjà citée.)
Mines de Bruay.	Bruay.	16 générateurs sch = 194 m^2.	Centrale de 15 tonnes-heure.
Papeteries Navarre.	Roanne.	8 chaudières.	Centrale de 6 tonnes-heure.
Mines de Frankeholtz.	Frankeholtz.	2 chaudières.	
Mines de Drocourt.	Henin-Lietard.	6 générateurs.	
Mines de Noeux.	Noeux-les-Mines.	6 générateurs.	
Nord-Ouest Electrique.	Bully-les-Mines.	4 chaudières.	Centrale de 6 tonnes-heure.
Ciment d'Alias-Marnac.	Paris.	1 chaudière Meunier de 250 m^2.	
Mines d'Aniche.	Aniche.	2 chaudières Meunier de 187 m^2.	
Sté. d'Elec. de Caen.	Caen.	1 chaudière.	Pulvéro-brûleur.
E. Marcesche.	Lorient.	1 chaudière.	,,
Mines, Fonderies et Forges d'Alais.	Alais.	1 chaudière.	,,
Papeterie de Rives.	Rives.	1 chaudière.	Pulvéro-brûleur et secheur.
Mines de Bruay.	Bruay.	1 chaudière Buttner.	Pulver (en marche depuis novembre 1920).
Progil.	Lyon.	1 chaudière.	Turbo-pulvérisateur.
Hts. Fourneaux de Brousseval.	Brousseval.	1 chaudière.	
Société Lorraine Minière et Métallurgique.		1 chaudière.	
Mines de Noeux.	Noeux.	1 chaudière Belleville.	Turbo - pulvérisateur (en marche depuis 4 mois).

Chaudières (Boilers).

Usines.	Situation.	Appareils.	Type d'Installation.
Energie Electrique du Nord de la France.	Wasquehal.	1 chaudière.	Turbo-pulvérisateur.
Compagnie Electrique de la Loire et du Centre.	Montlucon.	2 chaudières.	,,
Produite chimiques d'Alais et de la Carmarque.		1 chaudière.	Pulvéro-brûleur.
Marcheville - Daguin (Soudière).	La Madeleine. Meurthe-et-Moselle.	1 chaudière. McNicol.	,,
Aciéries de St. Etienne.	Saint-Etienne.	1 chaudière.	
Société Houillière du Nord d'Alais.	Saint-Martin de Valgalgues.	1 chaudière Buttner.	
Union d'Electricité.	Paris.	1 chaudière Garbe.	
Ateliers de Sedan.	Sedan.	2 chaudières.	
Mines de Bruay.	Bruay.	1 chaudière.	
Etablissement National d'Indret.	Indret.	1 chaudière.	Turbo-pulvérisateur.
Châtillon, Commentry et Neuves-Maisons.	Neuves-Maisons.	1 chaudière.	,,
Mines de Béthune.	Béthune.	2 chaudières.	
Aciéries de la Marine et d'Homécourt.	Saint-Chamond.	4 chaudières.	,,
Société Métallurgique de Knutange.	Knutange.	4 chaudières.	,,
Houillères de Saint-Etienne.	Saint-Etienne.		
Mines, Fonderies et Forges d'Alais.	Foncaris.	1 chaudière.	Pulvéro-brûleur.
MM. Bernard et Lament.	Lille.	1 chaudière.	Turbo-pulvérisateur.
Blanchisserie du XX siècle.	Boulogne.	1 chaudière.	,,
Turonles et Vraincourt.	Vraincourt.	2 chaudières.	,,

French Colonies.

Société Française de distillerie de l'Indo-Chine.		1 chaudière.	Pulvéro-brûleur.
Ciments Portland de l'Indo-Chine.	Haiphong.	B.W. t. 465 m².	

Belgium.

Fours (*Furnaces*).

Usines.	Situation.	Appareils.	Type d'Installation.
Société Dyle et Bacalan.	Louvain.	Fours.	
Société Ougrée-Marihaye.	Ougrée.	20 fours.	Centrale 30 tonne-heure (pouvant être doublée).
Cuivres et Metaux.	Hemixeur.	1 four de grillage.	Turbo-pulvérisateur.
G. Dumont.	Sclaigneaux.	1 four.	
Boulonnerie du Ruan.		1 four de boulonnerie.	
Espérance Londoz.	Liège.	1 four.	
Société Ougrée-Marihaye.	Louvain.	1 four poussant.	
Tôleries Delloye-Mathieu.	Huy.	1 four à souder.	
		1 four à réchauffer.	
Société John Cockerill.		1 four poussant.	
La Ville Montagne.	Baelen.	3 fours.	
Dumont Frères.	Sclaigneaux.	1 four.	
Athus-Grivegnée.		4 fours poussant.	
Sté. des Tubes de la Meuse.		3 fours poussant.	
Boulonnerie de la Blanchisserie.		1 four à tirefoints.	
Société Ougrée-Marihaye.	Ougrée.	30 chaudières.	Centrale de 30 tonnes-heure.
Lieminoir de la Rochette.		1 four à réchauffer.	Turbo-pulvérisateur.
Charbonnage d'Orange-Nasseau.	Herlen.	1 chaudière.	,,
L. Lagache.	Renaix.	1 chaudière.	
Charbonnage de Falisolle.		1 chaudière.	Pulvéro-brûleur.
Compagnie Auxiliaire Electrique d'Antoing.	Antoing - les - Tournai.	1 chaudière.	
Charbonnage de Trieu-Kaisin.	Châtilineau.	1 chaudière.	
Charbonnages d'Horme et Wasmes.	Wasmes.	2 chaudières.	
Gaz et Electricité du Hainaut.	Ville sur Haine.		
Centrale Electrique d'Entre.	Sambre-et-Meuse.	2 chaudières.	Turbo-pulvérisateur.
Sté. Franco-Belge.	Auvelois, La Croyere.	2 chaudières.	,,

Spain and Portugal.

Fours (Furnaces).

Usines.	Situation.	Appareils.	Type d'Installation.
Compagnie de la Cruz.		Fours.	
Altos Hornos.	Viscaya.	Fours et chaudières.	Turbo-pulvérisateur.
Mines Domaniales de la Lane.		1 chaudière.	,,
Mines d'Anzin.	Anzin.	1 chaudière.	,,
Energie Electrique du Nord de la France.		2 chaudières.	,,
Sucrerie Centrale de Cambrai.		1 chaudière.	,,
Cie. Thomson-Houston.	St. Ouen.	4 chaudières.	,,
Ca Anonima Basconia.	Bilbao.	1 four à réchauffer.	,,
S. M. Quijano los Corrales (31).	Santander.	1 four à réchauffer.	,,
Altos Homos Andaludia.	Malaga.	1 four à réchauffer.	,,
Real Compania Asturiana Aviles.		1 four à zinc.	
Sociedad Electro-Quimica de Flix.	Tarragone.	1 four rotatif.	
Hispano Suiza.	Barcelona.	1 four de forge.	
Sociedad Popular Ovetense.	Oviedo.	1 four.	
Sociedad Minera et Metallurgica de Penaroya.	Penaroya.	1 four.	Pulvéro-brûleur.
Sociedad Espanola de Construcciones Electro-Mecanicas.	Madrid.	1 four.	
MM. Ledoy Cie.	Barcelona.	1 four.	Turbo-pulvérisateur.
Sté. Métallurgique du Nord de Oporto.		1 four.	,,
Austaleria Espanolo.		1 four.	,,

Chaudières (Boilers).

Usines.	Situation.	Appareils.	Type d'Installation.
Sociedad General Azucarena de Espana.		1 chaudière.	,,
Ca Anonima Basconia.	Bilbao.	1 chaudière.	,,
Vinda e Hijos de Ivila.	Barcelona.	1 chaudière.	,,
Sté. Minière et Mét. de Penaroya.	Penaroya.	1 chaudière.	,,
Chemin de Fer Nord Espagne.		1 chaudière.	,,
Société Minière et Métallurgique de Penaroya.	Penaroya.	2 chaudières. 1 chaudière.	Pulvéro-brûleur.
Sociedad Industrial Asturiana.	Ovedo.	1 chaudière.	Turbo-pulvérisateur.
Sociedad Electro-Quimica de Flix.	Tarragone.	1 chaudière.	,,
Hijos de Solas Sert.	Barcelona.	1 chaudière.	Pulvéro-brûleur.
Sociedad Espanola de Construcciones Electro-Mecanicas.		1 chaudière.	,,
Savonneries Méridionales.	Utrera.	1 chaudière	Pulvéro-brûleur.
Ed. Guedes Lda.	Lisbon.	1 chaudière. Cornish de 95 m^2.	,,
Cie. Metallique del Norte de Oporto.	Oporto.	1 chaudière.	Turbo-pulvérisateur.

Italy.

Fours (Furnaces).

Usines.	Situation.	Appareils.	Type d'Installation.
Ansaldo et Cie.	Sampierdarena.	Fours à réchauffer et chaudières.	Centrale de 10 tonnes-heure.
Chem. de fer de l'Etat Italien.	Florence.	Locomotive.	
Sa Anna Ilva Acciaierie Italienne.	Bolzaneto.	1 four poussant.	Turbo-pulvérisateur.
Institute Spérimentale ferrovie dello Stato Roma.		1 four.	
Sa Anna de Monteponi.	Monteponi.	2 fours à grillage.	
Bernard Martinozzo et Cie.	Cagliari.	1 four de grillage	
Metallurgica Ossalonee.	Novara.	1 four.	Turbo-pulvérisateur.
		Chaudières.	
Sa Anna Gio Ansaldo et Cie. Acciaierie.	Cornigliano.	2 chaudières.	,,
Direzione delle Construzione navali.	Spezzia.	1 chaudière.	,,
MM. Michelin et Cie.	Turin.	1 chaudière.	,,

Germany.

Cie. Eschweiler Bergwerke-Verein.	Kohlscheid.	1 chaudière. 6 chaudières de 300 m^2. 2 chaudières de 500 m^2.	
Babcock-Werke.	Oberhausen.	1 chaudière.	Turbo-pulvérisateur.
Rheinische Westphalische Elektrizitäts Gm.	Essen.	1 garbe de 660 m^2.	

Luxembourg.

Ste. H.A.D.I.R.	Differdange.		Pulvéro-brûleur.

Holland.

Maastrichte Zinkwit Co.	Eysden.	Fours. Chaudières.	
Chemins de fer Neerlandais.		Locomotives.	
Amsterdam Corporation.		2 chaudières.	Turbo-pulvérisateur.

Sweden.

Chemins de fer Koheim 3 Jernoverls.		1 four à vidons.	Turbo-pulvérisateur.

Egypt.

Usines à Gaz.	Alexandria.	2 chaudières.	Pulvéro-brûleur.

Great Britain and Colonies.

Name of Works.	Situation.	Apparatus.	Type of Installation.
Babcock & Wilcox, Ltd.	Renfrew.	2 Reheating furnaces.	Aero-Pulveriser.
McKechnie Bros.	Widnes.	1 Copper Melting Furnace.	Central plant 10 tons per hour.
Stewarts & Lloyds, Ltd.	Glasgow.	1 Puddling Furnace.	Aero-Pulveriser.
The Wellington Tube Works.		1 Brazing Furnace.	
The Castner-Kellner Alkali Co.		1 Concentration Furnace.	
The Broughton Copper Co.	Manchester.	1 Copper Melting Furnace.	
Edgar Allen & Co.		1 Reheating furnace.	Aero-Pulveriser.
Scottish Tube Co., Ltd.	Motherwell.	1 Puddling Furnace. 1 Reheating Furnace.	Central Plant.
		1 Reheating Furnace.	Aero-Pulveriser.
Hammersmith Electric Light Station.	Hammersmith.	2 Stirling Boilers.	
John Thornycroft, Ltd.	Southampton.	1 Boiler.	Aero-Pulveriser.
Lambton & Hetton Collieries.	Durham.	1 Boiler.	,,
David Colville, Ltd.		1 Boiler.	,,
Price's Patent Candle Co.		1 Boiler.	,,

Australia.

Wallaroo & Moonta Mining Co.	Australia.	2 B. & W. de 295 m^2. 4 B. & W. de 170 m^2.	

India.

Central Electric.	Hyderabad.	4 Boilers.	Aero-Pulveriser.

BIBLIOGRAPHY

A Summary of Papers, Books, Articles and General Literature on the subjects of Pulverised Coal, which have been written by most of the adherents and engineers who advocate this method of applying coal for heating purposes, embracing early references 1879 to 1918 and more complete references for the years 1918 to 1923. Bulletins and Technical Papers on Fuel Subjects issued by the Department of Mines, Washington, U.S.A.

Recent Articles and Publications.

January 1 to July 31, 1923.

From "Engineering Societies Library," New York.

Arrowwood, M. W. . . . "Principles of Feeding Pulverised Fuels." February, 1923. *Combustion*, Vol. 8, pp. 117–22. (4000 w.)

,, ,, ... "Burning Pulverised Coal with Reduced Furnace Volumes." March 13, 1923. *Power*, Vol. 57, pp. 417–19. (2200 w.)

Atterbury, T. W. . . . "Burning Powdered Coal in Warm-air Furnaces." February 16, 1923. *Sheet Metal Worker*, Vol. 14, pp. 43–45. (1800 w.)

Behling, W. . . . "Pulverised Brown Coal Plant and Furnace at the Becker Steelworks, Willich, Germany." "Die Braunkohlenstaub-Erzeugungs- und Feuerungsanlagen der Stahlwerk Becker Akt.-Ges., Willich." March 22, 1923. *Stahl und Eisen*, Vol. 43, pp. 393–98. (3500 w.)

Blizard, J. . . . . "Preparation, Transportation and Combustion of Powdered Coal." 1923. *Bureau of Mines Bulletin*, 217. 127 pp.

Boyer, J. . . . . "Pulverised Coal-burning Central Station, Bruay Mines, France." March, 1923. *Mechanical Engineering*, Vol. 45, pp. 183–84. (1000 w.)

Brownlie, D. . . . . "'Lopulco' Pulverised Fuel Installation at Vitry." June, 1923. *Power Engineering*, Vol. 18, pp. 205–8 and 224. (2000 w.)

,, ,, ... "Development of Pulverised Fuel," April 13, 1923. *Chemical Trade Journal*, Vol. 72, pp. 443–44. (2400 w.)

Buell, R. N. . . . . "Electric Energy from Pulverised Brown Coal." December 27, 1922. *Australian Electrical Times*, Vol. 1, pp. 766–71. (3500 w.)

Butez, P. . . . . "Pulverised Coal-heating Plant at Ougrée-Marihaye Shops, Ougrée, Belgium." "Installation de chauffage par combustible pulvérisé aux établissements de la Société anonyme Ougrée-Marihaye Ougrée (Belgique)." April, 1923. *Chaleur et Industrie*, Vol. 4, pp. 327–31. (2000 w.)

Christie, A. G . . . "Pulverised Fuel for Power Plants." June 23, 1923. *Gas Age Recorder*, Vol. 51, pp. 791–92. (1000 w.)

,, ,, ... "Pulverised Fuel in Central Station Boiler-rooms." June 12, 1923. *Power*, Vol. 57, p. 951. (700 w.)

Crolius, F. G. . . . "Power Progress during 1922," "Powdered Fuel," etc. January, 1923. *Blast Furnace and Steel Plant*, Vol. 11, pp. 104–9. (3500 w.) 4 illus.

Dunn, T. J. . . . "Powdered Coal as Fuel." June 15, 1923. *Machinery Market*, pp. 33–34. (3000 w.)

,, ,, ... "Powdered Coal as Fuel." June 1, 1923. *Mechanical World*, Vol. 73, pp. 343–44. (1500 w.) Serial.

,, ,, ... "Powdered Coal as Fuel." May 18, 1923. *Mechanical World*, Vol. 73, p. 317. (1000 w.) Serial.

Dunn, T. J. . . . . "Powdered Coal as Fuel." May 11, 1923. *Mechanical World*, Vol. 73, pp. 300–1. (1000 w.)

" " . . . . "Powdered Coal as Fuel." April, 1923. *Engineering Review*, Vol. 36, pp. 306–9. (2400 w.)

" " . . . . "Powdered Coal as Fuel—with Discussion." April 13, 1923. *Colliery Guardian*, Vol. 125, pp. 881–82. (3500 w.)

" " . . . . "Powdered Coal—with Discussion." April 13, 1923. *Iron and Coal Trades Review*, Vol. 106, p. 534. (1500 w.)

" " . . . . "Powdered Coal as Fuel." Advance Copy. April 6, 1923. N.E. Coast Institute of Engineers and Shipbuilders. 8 pp.

Eaton, George B. . . . "Pulverised Coal in the Cement Industry." July, 1923. *Cement and Engineering News*, Vol. 35, pp. 37–40. (2500 w.)

" " . . . . "All Pulverised Coal is 'Good Coal.'" April 7, 1923. *Black Diamond*, Vol. 70, pp. 386–87. (1500 w.)

Frion, P. . . . . . "Heating Boilers and Furnaces in General with Pulverised Coal." "Le chauffage au charbon pulvérisé des chaudières et des fours en général." November, 1922. *Chimie et Industrie*, Vol. 8, pp. 974–88. Concluded. 10 illus.

Griest, E. E. . . . . "Use Powdered Coal for Malleable." May 10, 1923. *Iron Trades Review*, Vol. 72, pp. 1387–92. (4000 w.)

" " . . . . . "Use Powdered Coal for Malleable." May 3, 1923. *Iron Trades Review*, Vol. 72, pp. 1309–14. (4000 w.) Serial.

Haslam, R. T., and Harris, L. "Producer Gas from Powdered Coal." April, 1923. *Industrial and Engineering Chemistry*, Vol. 15, pp. 355–57. (1500 w.)

" " "Producer Gas from Powdered Coal." May, 1923. *Mass. Inst. of Tech. Bull.*, 76, Vol. 58, 7 pp.

Herington, C. F. . . . "Various Systems of Burning Pulverised Coal." June, 1923. *Blast Furnaces and Steel Plant*, Vol. 11, pp. 345–47. (2000 w.)

" " . . . . "Pulverised Coal—Its Utilisation in the Industries." May, 1923. *Combustion*, Vol. 8, pp. 307–11. (1500 w.)

" " . . . . "Pulverised Coal—Its Utilisation in the Industries." April, 1923. *Combustion*, Vol. 8, pp. 242–45. (2500 w.)

" " . . . . "Pulverised Coal—Its Utilisation in the Industries." March, 1923. *Combustion*, Vol. 8, pp. 174–78. (2000 w.)

Hobbs, J. C., and Heller, L. W. "Pulverised Fuel for Large Boilers." July, 1923. *Blast Furnaces and Steel Plant*, Vol. 11, pp. 403–7. (3500 w.)

Illingworth, S. R., assisted by Griffith, J. . . . . "The Analysis of Coal and its By-Products." London: The Colliery Guardian Co., Ltd., 30 and 31 Furnival St., Holborn, London, E.C. 4. 372 pp.

Johnson, J. B. . . . . "Powdered Coal for Reverberatory Furnaces." February, 1923. *Combustion*, Vol. 8, pp. 90–93. (2100 w.)

Knowles, E. R . . . . "Why Dry Coal before Pulverisation and Combustion?" May, 1923. *Combustion*, Vol. 8, pp. 311–12. (800 w.)

Kreisinger, H., and Blizard, J. "Tests of Large Boiler Fired with Powdered Coal." January, 1923. *U.S. Bureau Mines Repts. and Invest.*, No. 2438. 2 pp.

" " "Boiler Tests with Pulverised Coal." March, 1923. *Sugar*, Vol. 25, pp. 131–33. (1500 w.)

" " "Combustion of Powdered Coal." April, 1923. *U.S. Bureau of Mines Repts. and Invest.*, No. 2470. 6 pp.

" " "Combustion of Powdered Coal." March, 1923. *Industrial and Engineering Chemistry*, Vol. 15, pp. 249–51. (1200 w.)

Meade, R. K. . . . . "Nature, Preparation and Use of Pulverised Coal." July 14, 1923. *Rock Products*, Vol. 26, No. 14, pp. 35–36. (1700 w.)

" " . . . . "Nature, Preparation and Use of Pulverised Coal." June 30, 1923. *Rock Products*, Vol. 26, pp. 54–56. (2500 w.) Serial.

" " . . . . "Nature, Preparation and Use of Pulverised Coal." June 16, 1923. *Rock Products*, Vol. 26, pp. 22–23. (1000 w.)

" " . . . . "Nature, Preparation and Use of Pulverised Coal." June 2, 1923. *Rock Products*, Vol. 26, pp. 27–29. (1500 w.) Serial.

Norris, R. . . . . . "Explosive Tendencies of Pulverised Coal." February, 1923. *Indian Industry and Power*, Vol. 20, pp. 192–96. (3500 w.)

North, F. K. . . . . "Powdered Coal used Exclusively in this Industrial Plant." January 16, 1923. *Power*, Vol. 57, pp. 84–87. (1800 w.)

O'Brien, T. H. . . . "Will Pulverised Coal be Substituted for Fuel Oil in Smelting Operations?" June 21, 1923. *Coal Age*, Vol 23, pp. 1013–14. (1500 w.)

Petri, G. . . . . "A New Pulverised Coal Furnace." "Eine neue Kohlenstaubfeuerung." April, 1923. *Archiv Wärmewirtschaft*, Vol. 4, pp. 65–66. (800 w.)

Rank, H. L. . . . "The Preparation and Burning of Pulverised Coal." April, 1923. *Industries Illustrated*, Vol. 4, pp. 18–20, 28, 30, and 33. (1800 w.)

Rice, G. S. . . . . "Coal Dust as an Explosive Agent." June 22, 1923. *Colliery Guardian*, Vol. 125, pp. 1575–76. (1400 w.)

Roberts, W. B. . . . "System of Pulverised Coal Meets Specific Needs." February 20, 1923. *Power House*, Vol. 16, pp. 23–27. (2500 w.)

Savage, H. D. . . . "Pulverised Fuel." June, 1923. *Combustion*, Vol. 8, pp. 389–90, 395, and 409. (3000 w.)

" " . . . . "Advantages to be Gained from Pulverising Canadian Fuels." June, 1923. *Journal Engineering Institute of Canada*, Vol. 6, pp. 271–80. (6500 w.)

Schaffer, H. A. . . . "Use of Pulverised Coal." June 11, 1923. *Chemical and Metallurgical Engineering*, Vol. 28, pp. 1024–25. (1500 w.)

" " . . . . "Use of Pulverised Coal." May 8, 1923. *Power*, Vol. 57, pp. 718–19. (1500 w.)

Scheffler, F. A. . . . "Maximum Conservation of Coal obtained only when Pulverised." February, 1923. *Combustion*, Vol. 8, pp. 112–13. (1100 w.)

Schulte, F. . . . "Recent Devices for Coal-dust Firing." "Neuere Einrichtungen und Erfahrungen auf dem Gebiete der Kohlenstaubfeuerung." May 31, 1923. *Ztsch. Bayer. Revisions-Vereins*, Vol. 17, pp. 74–78. (2500 w.)

" " . . . . "Recent Devices for Coal-dust Firing." "Neuere Einrichtungen und Erfahrungen auf dem Gebiete der Kohlenstaubfeuerung." May 15, 1923. *Ztsch. Bayer. Revisions-Vereins*, Vol. 27, pp. 69–72. (1800 w.) Serial.

" " . . . . "Recent Devices for Coal-dust Firing." "Neuere Einrichtungen und Erfahrungen auf dem Gebiete der Kohlenstaubfeuerung." April 30, 1923. *Ztsch. Bayer. Revisions-Vereins*, Vol. 27, pp. 62–64. (1000 w.)

" " . . . . "Coal-dust Furnaces for Steam Boilers in the Bruay Mines Power Plant." "Kohlenstaubfeuerungen für Dampfkessel im Kraftwerk der Bruay-Gruben." April 14, 1923. *Glückauf*, Vol. 59, pp. 362–66. (4000 w.)

" " . . . . "Recent Devices for Coal-dust Firing." "Neuere Einrichtungen und Erfahrungen auf dem Gebiete der Kohlenstaubfeuerung." March 10, 1923. *Glückauf*, Vol. 59, pp. 240–47. (4500 w.) Concluded.

" " . . . . "Recent Devices for Coal-dust Firing." "Neuere Einrichtungen und Erfahrungen auf dem Gebiete der Kohlenstaubfeuerung." March 3, 1923. *Glückauf*, Vol. 59, pp. 205–8. (3000 w.) Serial.

Sinnatt, F. S., and Slater, L. "Powdered Coal." July, 1923. *Fuel in Science and Practice*, Vol. 2, pp. 175–81. (4000 w.)

" " "Powdered Coal." June, 1923. *Fuel in Science and Practice*, Vol. 2, pp. 142–46. (2500 w.) Serial.

Sohm, M. . . . . "Firing Boilers with Powdered Coal at Bruay Colliery." December, 29, 1922. *Colliery Guardian*, Vol. 124, pp. 1583–85. (300 w.) (From *Rev. Indus. Minerale.*)

Tenney, E. H. . . . "Pulverised Coal." July, 1923. *Combustion*, Vol. 9, pp. 55–73. 18 pp.

Verdinne, H. . . . "Technique of Powdered Fuel Firing." June, 1923. *Fuel in Science and Practice*, Vol. 2, pp. 146–51. (5500 w.) (From *Rev. Univ. des Mines.*)

Wulf, O. . . . . "Fuller Powdered Coal Furnace." "Die Fuller-Kohlenstaubfeuerung." January, 26 1923. *Wärme*, Vol. 46, pp. 35–38. (2400 w.) Serial.

"Advantages of Pulverising Coal for Firing Smelting Furnaces, etc." June 15, 1923. *Salt Lake Mining Review*, Vol. 25, pp. 19–20. (800 w.)

"Apco Unit Pulverised Coal System." May 1, 1923. *Power*, May 1, 1923, Vol. 57, pp. 682–83. (1200 w.)

"Development of Pulverised Fuel." April 20, 1923. *Colliery Guardian*, Vol. 125, p. 947. (600 w.)

"Development of Pulverised Fuel." April 27, 1923. *English Mechanic*, Vol. 117, pp. 161–62. (1000 w.)

"Heating with Pulverised Coal." "Le chauffage au charbon pulvérisé." February 17, 1923. *Genie Civil*, Vol. 82, pp. 154–56. (1300 w.)

"'Lopulco' System of Pulverised Fuel Firing." May 25, 1923. *Iron and Coal Trades Review*, Vol. 106, p. 790. (800 w.)

"New Method of Powdered Fuel Firing." June 14, 1923. *Foundry Trade Journal*, Vol. 27, pp. 472–73. (1200 w.)

"Powdered Coal as Fuel." April 13, 1923. *Chemical Trade Journal*, Vol. 72, pp. 444–46. (2400 2.)

"Powdered Coal as Fuel in Steam Plants." February 2, 1923. *Colliery Guardian*, Vol. 125, pp. 263–64. (2400 w.)

"Providence Plant Instals Pulverised Fuel Equipment." May 1, 1923. *Power*, Vol. 57, pp. 680–81. (1200 w.)

"Pulverised Fuel Plant at Providence." April 28, 1923. *Electrical Railway Journal*, Vol. 61, pp. 725–27. (3000 w.)

"Recovery of Dusts and their Utilisation as Pulverised Fuel." "Récupération des poussières et leur utilisation comme combustible pulvérisé." April, 1923. *Chaleur et Industrie*. Supplement, p. 31. (600 w.)

PULVERISED COAL

Articles in the English and American Press (Period 1918–1922.)

Editorial.

"The Question of Powdered Fuel." *American Drop Forger*, July, 1918, p. 256.

"Pulverised Coal and Its Future." *American Gas Engineering Journal*, Vol. 112, 1920, pp. 4–6.

"The Use of Coal in Pulverised Form." (3000 w.) *Bulletin of American Institute of Mining Engineers*, No. 143, November, 1918, pp. 1678–84.

"Is Pulverised Coal a Bad Fire Risk ?" (300 w.) *Journal of American Society of Heating and Ventilating Engineers*, October, 1920. From *National Underwriter*.

"Developing Use of Pulverised Lignite." (300 w.) *Journal of American Society of Heating and Ventilating Engineers*, November, 1920.

"Some Comments on Pulverised Coal for Power Plants." *Journal of American Society of Heating and Ventilating Engineers*, Vol. 27, March, 1921, p. 207.

"Pulverised Fuel being Used for Heating." (1000 w.) *Black Diamond*, June 4, 1921.

"A Review of Powdered Coal Development." (2000 w.) *Black Diamond*, March 19, 1921.

"Discussion of Article on Powdered Coal." *Blast Furnace and Steel Plant*, August, 1918, Vol. 6, pp. 345, and following.

"Falcon Steel Company Operate Sheet Mill. Modern Plant uses Powdered Coal Fuel." *Blast Furnace and Steel Plant*, Vol. 8, 1920, pp. 274–80.

"Pulverised Low-Grade Coals Successfully Employed." *Canadian Engineer*, Vol. 39, 1920, pp. 172–3.

"Rolling Mill Uses Pulverised Coal." (500 w.) *Canadian Engineer*, October 14, 1920.

"Engineering at the Canadian Exhibition." *Canadian Machinery*, September 5, 1918.

"Rolling Mill Uses Pulverised Coal." (700 w.) *Canadian Manufacturer*, October, 1920.

"Burning Pulverised Coal as a Fuel." (1000 w.) *Cement, Mill and Quarry*, February 5, 1922.

"Introduction of Powdered Coal made in Cement Plants." (1500 w.) *Cement, Mill and Quarry*, May 20, 1921.

"Powdered Coal for Igniting D. and L. Roasters." (200 w.) *Chemical and Metallurgical Engineering*, December 15, 1918.

"Pulverised Coal." (1000 w.) *Chemical and Metallurgical Engineering*, February 9, 1921.

"Milwaukee Plant Exhibits a Drift Towards Use of Coal Dust in Power Plants." (1500 w.) *Coal Age*, May 25, 1922.

"Progress in Utilising Pulverised Fuel." (3500 w.) *Coal Age*, May 29, 1919.

"Powdered Coal as a Fuel." (900 w.) *Coal Age*, May 19, 1921.

"Ball Mills Pulverise Coal almost without Repair and Attendance Costs and with Minimum Power." (3000 w.) *Coal Age*, November 24, 1921.

"High Efficiency of Powdered Coal as Fuel." (1200 w.) *Coal Trade Journal*, August 13, 1919. Serial.

"Powdered Coal." (3500 w.) *Colliery Guardian*, May 5, 1922. From *Bulletin of Canadian Department of Mines.*

"Powdered Fuel." (2200 w.) *Colliery Guardian*, June 10, 1921.

"Great Power Project goes to Pulverised Fuel." (1500 w.) *Combustion*, September, 1922.

"Burning Coal like Oil at the Mine." (1500 w.) *Combustion*, September, 1922.

"Mixer and Feeder for Powdered Coal." *Compressed Air Magazine*, Vol. 23, August, 1918, p. 843.

"Powdered Coal Plant with Compressed Air Transport." *Electric Railway Journal*, Vol. 55, 1920, pp. 817–18.

"Milwaukee's Powdered Coal Station." (5400 w.) *Electric Railway Journal*, April 15, 1922.

"Status of Powdered Fuel." (3000 w.) *Electric Railway Journal*, July 30, 1921.

"New Processes for Treating." (600 w.) *Electric Railway Journal*, August 13, 1921.

"Powdered Coal Substitution for Fuel Oil at Seattle." *Electrical Review*, October 5, 1918.

"Pulverised Coal Tests Conducted at Milwaukee." *Electrical Review*, October 19 and 26, 1918.

"Pulverised Coal and Colloidal Fuel." (1500 w.) *Electrical Review*, December 24, 1920.

"Pulverised Coal in a Milwaukee Power Plant." *Electrical Review*, Vol. 76, 1920, pp. 469–72.

"Operating Results with Pulverised Coal." *Electrical Review*, Vol. 76, 1920, p. 506.

"Pulverised Coal an Effective Means of Fuel Economy." (700 w.) *Electrical Review*, January 22, 1921.

"Pulverised Coal Equipment for Steam Boilers." (450 w.) *Electrical Review*, January 8, 1921.

"Pulverised Fuel: with Special Reference to the Unit System." (1200 w.) *Electrical Times*, May 11, 1922.

"Powdered Fuel for Hammersmith." (1500 w.) *Electrical Times*, March 13, 1919.

"First Power Plant to use Pulverised Fuel Exclusively." *Electric Traction*, Vol. 18, April, 1922, pp. 328–38.

"First Large Plant using Pulverised Coal Exclusively." (2200 w.) *Electrical World*, April 15, 1922.

"Powdered Coal Plant for Hammersmith." (1200 w.) *Electrician*, June 27, 1919.

"Powdered Fuel for Electrical Purposes." (1000 w.) *Electrician*, August 5, 1921.

"The Growing Interest in Pulverised Fuel." (800 w.) *Electric Journal*, January 1, 1919.

"Instruction for Safe Use of Pulverised Coal." (2000 w.) *Engineer*, Vol. 127, 1919, pp. 398–9.

"Aero-Pulveriser." *Engineer*, Vol. 129, 1920, pp. 306–7.

"Pulverised Coal as Fuel in the United States." (5000 w.) *Engineer*, December 16 and 23, 1921.

"Pulverised Coal on American Locomotives." *Engineer*, August 25 and 30, 1918.

"Pulverised Fuel Locomotive." (3000 w.) *Engineer*, April 25, 1919.

"Use of Pulverised Coal." (3760 w.) *Engineer*, July 11 and 18, 1919.

"A Pump for Powdered Coal." (600 w.) *Engineer*, March 31, 1922.

"Pulverised Coal for Copper Smelter Furnaces." (1000 w.) *Engineer*, May 20, 1921.

"'Atritor' Coal-Pulverising Machine." (1800 w.) *Engineering*, July 14, 1922.

"Firing with Coal Dust." *Engineering*, May 17, 1918.

"Apparatus for Burning Powdered Coal." *Engineering and Industrial Management*, Vol. 2, 1919, p. 325.

"Pulverised Fuel Boiler." (1000 w.) *Engineering Review*, Vol. 34, May, 1921, pp. 288–9.

"Use of Pulverised Coal Making Steady Progress." (500 w.) *Engineering World*, January, 1921.

"Pulverised Coal an Efficient Means of Fuel Economy." (500 w.) *Engineering World*, Vol. 18, March, 1921, pp. 183. From *Commerce Monthly*.

"Coal-Dust Fired Reverberatory Furnaces in Chile." *Engineering and Mining Journal*, July 6, 1918.

"A Series of Discourses on Use of Powdered Anthracite and Recovery and Use of River Coal." *Journal of Engineers' Club of Philadelphia*, February, 1921.

"Melting Iron with Powdered Coal." *Foundry*, Vol. 48, 1920, pp. 136–39.

"Powdered Fuel in Open-Hearth and Small Heating Furnaces." *Foundry Trade Journal*, Vol. 20, May, 1918, p. 265.

"The Turbo Pulveriser." (900 w.) *Foundry Trade Journal*, January 12, 1922.

"Pulverised Coal." (720 w.) *Foundry Trade Journal*, Vol. 21, June, 1919, pp. 418–19.

"Utilisation of Waste Farm Products for Fuel." (500 w.) *Indian Engineering*, June 25, 1921.

"Pulverised Brown Coal for Steam Raising." (2000 w.) *Industrial Australia*, September 9, 1920.

"Fuel Economy: Use of Pulverised Brown Coal in Melbourne." (3000 w.) *Industrial Australia*, October 27, 1921.

"Report of Standing Committee on Pulverised Fuel." (7600 w.) *Proceedings of International Railway Fuel Association*, May 24–26, 1920.

"Pulverised Coal Burning." (300 w.) *Iron Age*, December 29, 1921.

"Advantages of Powdered Coal as a Fuel." *Iron Age*, August 15, 1918.

"New Mill to Roll Automobile Sheets." (2500 w.) *Iron Age*, November 4, 1920.

"For Burning Powdered Coal." *Iron Age*, December 16, 1920, and Vol. 104, 1920, p. 444.

"Pulverised Coal in Boiler and Furnace." *Iron Age*, Vol. 104, 1919, pp. 709–10.

"Burning Pulverised Coal in a Sheet Mill." *Iron Age*, Vol. 104, 1920, pp. 1167–72.

"Pulverised Coal in the Malleable Foundry." *Iron Age*, Vol. 105, 1920, pp. 259–61.

"Pulverised Coal *versus* Stokers for Boilers." *Iron Age*, Vol. 105, 1920, pp. 1798–1800.

"Boiler Firing with a Turbo Pulveriser." (1000 w.) *Iron and Coal Trades Review*, August 4, 1922.

"A New Pulverised Fuel Plant." (1500 w.) *Iron and Coal Trades Review*, March 24, 1922.

"Powdered Fuel under Steam Boilers." (1200 w.) *Iron and Coal Trades Review*, June 9, 1922.

"Pulverised Coal Firing." *Iron and Coal Trades Review*, September 6, 1918.

"The Turbo Pulveriser." (800 w.) *Iron and Coal Trades Review*, December 16, 1921.

"Powdered Coal." (400 w.) *Iron and Coal Trades Review*, October 4, 1918.

"Powdered Coal for Firing Steam Boilers." (800 w.) *Iron and Coal Trades Review*, March 14, 1919.

"Pulverised Coal in Blast Furnaces." *Iron and Coal Trades Review*, Vol. 99, 1919, pp. 204–5.

"The Use of Powdered Coal." (400 w.) *Metal Industry*, December 3, 1920.

"Pulverised Coal." *Mining and Scientific Press*, June 22, 1918.

"Pulverised Coal." *Mining and Scientific Press*, September 7, 1918.

"Pulverised Coal." (500 w.) *Mining and Scientific Press*, December 10, 1921.

"Powdered Coal as a Substitute for Oil Fuel." *Mining and Scientific Press*, Vol. 118, 1919, pp. 235–36.

"Pulverised Fuel in the Oneida Street Plant of the T.M.E.R. & L., Co." *National Engineer*, October, 1918, pp. 535–9.

"Pulverised Coal as a Fuel." (300 w.) *Oil and Gas Journal*, January 7, 1921.

"Powdered Coal Development." (1000 w.) *Pacific Builder and Engineer*, December 31, 1920. (1200 w.) January 28; (900 w.) February 25; (1600 w.) March 25, 1921.

"Largest Station Using Pulverised Coal." (3000 w.) *Power*, April 18, 1922.

"Excellent Results with Pulverised Coal at Milwaukee." *Power*, October 15, 1918.

"Burning Powdered Coal Successfully." (1000 w.) *Power*, January 21, 1919.

"Burning Fine Anthracite and Bituminous Coal." (1500 w.) *Power*, January 28, 1919.

"The Use of Oil in Cleaning Coal." *Power*, August 2, 1921.

"Pulverised Coal System for Small Plants." *Power*, December 27, 1921.

"Pulverised Fuel for the Railways." *Power*, Vol. 49, 1919, pp. 997; Vol. 50, 1919, pp. 516–17.

"Four Days Test on Oneida Street Boilers Burning Pulverised Coal." *Power*, Vol. 51, 1920, pp. 354–7.

"Washery Sludge Burned in Pulverised Form at Seattle." *Power*, Vol. 51, 1920, pp. 729–31.

"New Lakeside Pulverised Coal Plant, Milwaukee." *Power*, Vol. 52, 1920, pp. 358–60.

"A Description of the Bettington Boiler." (1000 w.) *Power House*, July 5, 1921.

"Powdered Fuel Tests." *Power Plant Engineering*, August 1, 1918.

"Powdered Coal and Its Equipment." *Power Plant Engineering*, Vol. 23, 1919, pp. 1006–9.

"Pulverised Coal." (3270 w.) *Power Plant Engineering*, August 1, 1919.
"Boiler Furnaces for Gas, Oil and Pulverised Coal." (1800 w.) *Power Plant Engineering*, December 1, 1920.
"Pulverised Coal." (3500 w.) *Power Plant Engineering*, January 1, 1921.
"Powdered Graphite Coals." (500 w.) *Power Plant Engineering*, May 1, 1921.
"Economic Features of Pulverised Coal Firing." (600 w.) *Practical Engineer*, October 6, 1921.
"New Method of Burning Powdered Coal." *Queensland Government Mining Journal*, August 15, 1918. From *Iron Agc.*
Annual Convention of Fuel Association. Papers on French Fuel Conditions, Pulverised Coal, and Feed-Water Heaters. (9500 w.) *Railway Age*, May 27, 1921.
"'Lopulco' Feeder for Pulverised Fuel." *Railway Engincer*, Vol. 39, September, 1918, p. 179.
"'Lopulco' Feeder for Pulverised Fuel." *Railway and Locomotive Engineering*, June, 1918, p. 197.
"Pulverised Fuel in Stationary Boilers." *Railway and Locomotive Engineering*, September, 1918, p. 294.
"Locomotive Pulverised Fuel Equipment." (1500 w.) *Railway Mechanical Engineer*, Vol. 93, August, 1919, pp. 498–500.
"The 'Lopulco' Mixer and Feeder for Powdered Coal." *Railway Review*, Vol. 63, July 6, 1918.
"Powdered Fuel Burning Apparatus for an Australian Railway." (1500 w.) *Railway Review*, March 22, 1919.
"Locomotive Powdered Fuel Burning Apparatus on Great Central Railway." *Railway Review*, Vol. 66, 1920, pp. 410–11.
"Use of Pulverised Lignite for Fuel in Australia." (400 w.) *Scientific American*, October 23, 1920.
"Advantages and Increasing Use of Pulverised Coal." *Scientific American*, June 8, 1918.
"Powdered Coal Application to Central Power and Heating Station." (2500 w.) *Steam*, Vol. 29, May, 1922, pp. 131–3.
"Pulverised Coal." (1200 w.) *Steam*, Vol. 28, December, 1921, pp. 163–4.
"Powdered Coal in a Malleable Iron Foundry." *Steam*, July, 1918, p. 8.
"Pulverised Fuels." (300 w.) *Steam*, Vol. 22, November, 1918, p. 121.
"Puget Sound Traction Light and Power Company's Pulverised Coal Plant." *Stone and Webster Journal*, Vol. 25, 1919, pp. 96–109.
"Pulverised Coal for Steam Boilers." *Textile World Journal*, Vol. 58, 1920, pp. 1523–5.
"Pulverised Fuel. Progress and Application." (1500 w.) *Times Engineering Supplement*, May, 1919, p. 162.
"Pulverised Fuel. Trials with Morwell Brown Coal." (700 w.) *Times Trade Supplement*, December 17, 1921.
"Pulverised Coal." (1500 w.) *Traveller's Standard*, Vol. 9, September, 1921, pp. 183–7.
"Pulverised Coal Hazard." (1800 w.) *Universal Engineer*, Vol. 34, December, 1921, pp. 30–31. From *Travellcr's Standard.*
"Pulverised Coal Hazard." (700 w.) *Univcrsal Engineer*, Vol. 35, March, 1922, p. 27.

PULVERISED COAL.

Articles in the English and American Press (Period (1918–1922)

Authors.

Adamson, A. V. . . . "The Use of Coal in Pulverised Form." (1500 w.) *Bulletin of American Institute of Mining Engineers*, December, 1916, pp. 1771–75.
,, ,, ... "Notes on Powdered Coal." (500 w.) *Mining and Scientific Press*, January 18, 1919.
Anderson, J. . . . . "Pulverised Fuel in a Milwaukee Power Plant." *Railway Review*, Vol. 63, October 26, 1918, pp. 606–7.
,, ,, ... "Pulverised Coal for Central Station Boilers." (3000 w.) *Combustion*, April, 1920, pp. 24–6.
,, ,, ... "Pulverised Coal for Central Station Boilers." (3000 w.) *Power*, Vol. 51, 1920.

Anderson, J. . . . . "Using Pulverised Coal in Central Stations." (3000 w.) *Power House*, Vol. 14, May 20, 1921, pp. 28–9, 33.

" " . . . . "Pulverised Coal for Fuel Makes Good Saving at Milwaukee." *Electric Railway Journal*, Vol. 55, 1920.

" " . . . . "Tests of Pulverised Fuel Equipment." *Combustion*, Vol. 2, 1920.

Arrowwood, M. W. . . "Principles of Feeding Pulverised Fuel" (2500 w.) *Combustion*, July, 1922; (2500 w.) *Combustion*, August, 1922; (1500 w.) *Combustion*, September, 1922.

" " . . . . "Develop Firing System for Air Furnace." *Foundry*, Vol. 47, 1919.

Atkinson, J. S. . . . "The Application of Pulverised Fuel to Metallurgical Furnaces and Steam Boilers." (4000 w.) *Machinery Market*, August 30, 1918, and *Iron and Coal Trades Review*, May 16, 1919.

" " . . . . "Combustion of Powdered Fuel." (2500 w.) *Electrician*, June 27, 1919.

" " . . . . "Powdered Fuel: Recent Developments in Connection with the Firing of Metallurgical Furnaces" (1800 w.); *Iron and Coal Trades Review*, December 2, 1921; *Engineering and Industrial Management*, December 15, 1921 (1200 w.); *Metal Industry*, December 23, 1921 (2200 w.)

Atterbury, T. W. . . "Burning of Powdered Coal in Household Furnaces." (1800 w.) *Engineers and Engineering*, June, 1922.

" " . . . . "Powdered Coal for Malleable." (3500 w.) *Foundry*, November, 1922.

Barnhurst, H. G. . . "Powdered Fuel in Open Hearth and Small Heating Furnaces." *Iron and Coal Trades Review*, April 12, 1918.

" " . . . . "General Utilisation of Pulverised Coal." *Chemical Engineering and Mining Review*, March 5, 1918.

" " . . . . "El Carbon en Polvo Como Combustible." *Bol. de la Sociedad de Fomento Fabril*, May, 1918.

" " . . . . "Pulverised Coal as a Fuel." (Extract of Paper read before Cleveland Engineering Society.) *Machinery*, June 19, 1918.

" " . . . . "Pulverised Coal and Its Utilisation." (2000 w.) *Engineering World*, January 15, 1919.

" " . . . . "Pulverised Coal—Its Utilisation." (400 w.) *Concrete*, February, 1919.

" " . . . . "Pulverised Coal and its Bearing on the Fuel Situation." (1500 w.) *American Fertiliser*, April 26, 1919.

" " . . . . "Why and How of Pulverised Coal." (1800 w.) *Coal Trade Journal*, October 13, 1920.

" " . . . . "Pulverised Coal and Its Future." (3300 w.) *Steam*, October, 1920, and *Universal Engineer*, Vol. 32, 1920.

" " . . . . "Pulverised Coal for Boiler Firing." (5000 w.) *A.S.R.E. Journal*, November, 1920.

" " . . . . "Pulverised Coal for Boiler Firing." (6000 w.) *Refrigeration*, July, 1921.

" " . . . . "Pulverised Coal in the Power Plant." (1000 w.) *Combustion*, November, 1921.

" " . . . . "Pulverised Coal for Stationary Boilers." *Combustion*, Vol. 2, 1920.

Bates, L. W. . . . . "Colloidal Fuel." (2700 w.) *Steam*, August, 1922.

Blizard, J. . . . . . "Powdered Coal." (5800 w.) *Colliery Guardian*, April 13 and 21, 1922. (From *Bulletin of Canadian Department of Mines*.) Serial Article.

Bourcoud, A. E. . . . "Gasification of Powdered Coal." (3000 w.) *Chemical and Metallurgical Engineering*, April 6, 1921.

Bromley, C. H. . . . "Washery Sludge burned in Pulverised Form at Seattle." (2200 w.) *Stone and Webster Journal*, September, 1920.

Buell, R. N. . . . . "Economic Use of Pulverised Brown Coal." (2000 w.) *Chemical Engineering and Mining Review*, September 5, 1920.

Clark, S. N. . . . . "Pulverised Coal *versus* Stoker Firing." *Electrical World*, December 25, 1920. (500 w.)

Clark, S. N. . . . . "Pulverised Coal as a Fuel under Steam Boilers." (700 w.) *Engineering World*, February, 1922.

Cochrane, H.S.B.W. Corporation . . . . . "Powdered Coal and its Combustion under Boilers." *Finding and Stopping Waste in Modern Boiler Rooms*, 2nd edition, Vol. 2, 1921.

Coffin, E. P. . . . . "Scope of Pulverised Coal." (3000 w.) *Combustion*, August 1921.

,, ,, ... "Pulverised Coal in the Iron and Steel Industry." (2000 w.) *Chemical and Metallurgical Engineering*, November 23, 1921.

,, ,, ... "Pioneer Boilers fired with Pulverised Coal." (2500 w.) *Combustion*, February, 1922.

,, ,, ... "Burning Pulverised Fuel." (2500 w.) *Combustion*, April, 1922.

,, ,, ... "The Extent of the Use of Pulverised Coal in the Industries and its Possibilities in the War." May, 1918.

Colbert, C. L. . . . . "Improvements in Nodulising at Chrome, N.J." (2000 w.) *Engineering and Mining Journal*, August 13, 1921.

Cole, A. C. . . . . . "Operating by Powdered Coal to Save Fuel." *Blast Furnace and Steel Plant*, Vol. 8, 1920.

Collins, H. R. . . . . "Use of Coal in Pulverised Form." *Colliery Guardian*, May 10, 1918. (Paper presented to American Institute of Mining Engineers.)

,, ,, ... "Use of Coal in Pulverised Form." *Colliery Guardian*, September 13, 1918.

,, ,, ... "First Pulverised Coal Installation in Western Canada." (2200 w.) *Mining and Engineering Record*, September 30, 1918.

,, ,, ... "Use of Coal in Pulverised Form." (1000 w.) *Queensland Government Mining Journal*, January 15, 1919.

Corbet, D. . . . . . "Saw Mill Refuse, Powdered Coal and Oil Fuels." *Journal of American Institute of Mechanical Engineers*, Vol. 39, 1920, pp. 115–32.

Costello, W. H. . . . . "Magnetic Separator Pulleys in Coal Plants." (1800 w.) *Blast Furnace and Steel Plant*, June, 1921.

Cridge, Ralph H. . . . "Pulverised Coal." (2200 w.) *Electrical Times*, January 13, 1921.

Crolius, F. J. . . . . "Pulverised Firing in Steam Generation." Association of Iron and Steel Electrical Engineers, June, 1921, and *Blast Furnace and Steel Plant*, July, 1921.

Cross, B. J. . . . . "Distributing Pulverised Coal to Small Plants." *Coal Age*, Vol. 17, 1920, pp. 635–37.

Coutant, J. G. . . . . "French Mine Uses Pulverised Anthracite." (1000 w.) *Combustion*, October, 1922.

Cunliffe, J. . . . . "Pulverised Coal for Industrial Purposes." (2000 w.) *Coal Age*, May 25, 1918; *Colliery Guardian*, July 12, 1918; *Queensland Government Mining Journal*, December, 1919; and *Mechanical World*, April 27, 1918.

,, ,, ... "Pulverising Coal." (1200 w.) *Engineering and Cement World*, November 15, 1918.

,, ,, ... "The Growing Use of Pulverised Coal." (1200 w.) *Contract Record*, December 11, 1918.

Delaney, C. H. . . . . "Use of Pulverised Californian Coal." (2000 w.) *National Engineer*, June, 1919.

,, ,, ... "Oil and Powdered Fuel for Central Stations." *Electrical World*, Vol. 75, 1920, pp. 128–9.

Dick, W. J. . . . . "Pulverised Fuel: Its Use and Possibilities." *Canadian Commission of Fuel Conservation*, 1919.

,, ,, ... "The Possibilities of Pulverised Fuel." *Power House*, Vol. 13, 1920, pp. 116–19.

Dille, C. A. . . . . "Pulverised Coal in an Industrial Plant." (1500 w.) *Power Plant Engineering*, February 15, 1919.

Dixon, A. J. . . . . "Operation with Pulverised Coal." *Power*, July 5, 1921.

Dovey, J. T., and Calkins, G. N. . . . . "Utilisation of Pulverised Coal." *Bulletin of Canadian Institute of Mining and Metallurgy*, September, 1922.

Dubriel, O. F. . . . "Firing Pulverised Fuel." *National Engineer*, June, 1921.

Dwyer, P. . . . . "Apply Powdered Coal to Air Furnace." (4000 w.) *Foundry*, December 15, 1921.

" " . . . . "Foundry Produces Malleable for Own Use." *Iron Trade Review*, August 31, 1922.

Fitch, W. H. . . . "Pulverised Coal in Open Hearth Practice." *Iron Age*, Vol. 104, 1919.

Foster, J. T. . . . "Pulverised Coal Burners *versus* Stokers." (800 w.) *Electrical World*, March 8, 1919.

Fry, L. H. . . . . "Pulverised Coal as Fuel." (4500 w.) *Engineering*, November 12, 1920.

Fuller, J. W. . . . "Application of Pulverised Coal to Boilers." (1200 w.) *Mining and Metallurgy*, December, 1921.

Gaffney, J. B. . . . "United States Nitrate Plant No. 2." *Cement, Mill and Quarry*, Vol. 16, 1920, pp. 15–20.

Gale, C. H. . . . "Anneal Steel with Pulverised Coal." *Foundry*, January 1, 1921.

Gentine, H. I. . . . "Atomised Fuel—Its Composition and Combustion." (1800 w.) *Steam*, August, 1921.

Goodwin, C. J. . . . "Pulverised Fuel in Chemical Factories and Waste Heat Boilers." (4500 w.) *Engineering and Industrial Management*, July 31, 1919.

Greisen, E. C. . . . "Preparing and Distributing Powdered Coal." (1500 w.) *Iron Age*, February 2, 1922.

Grindle, A. J. . . . "Powdered Coal Applied in Foundry." (2000 w.) *Foundry*, August 1, 1921.

" " . . . . "Powdered Coal for the Small Foundry." *Foundry*, Vol. 47, 1919.

Grounds, A. . . . "Notes on Patent Fuel." (4300 w.) *Fuel*, July 28, 1922.

Hadfield, Sir Robert . . "Pulverised Coal." Presidential address to Society of British Gas Industries, April 18, 1918.

Hall, R. D. . . . "Advantages of River Coal and Pulverised Anthracite Canvassed by Engineers." (2000 w.) *Coal Age*, December 23, 1920.

" " . . . . "Engineers Afforded Latest Information on Powdered Coal and Briquettes." (1200 w.) *Coal Age*, January 6, 1921.

Hamilton, E. H. . . . "Firing Assay Muffles with Powdered Coal." (300 w.) *Mining and Metallurgy*, December, 1921.

" " . . . . "Powdered Coal in the Lead Blast Furnace." (1500 w.) *Mining and Metallurgy*, October, 1922.

Harbord, F. W. . . . "Advances in Metallurgy During the War." (4000 w.) *Iron and Steel of Canada*, July, 1921. Presidential Address before the Institute of Mining and Metallurgy.

Harrington, J. . . . "Use of Oil and Powdered Coal as Fuel." (2500 w.) *Power House*, June 5, 1919.

Harrison, N. C. . . . "Pulverised Coal as a Fuel." (4500 w.) Abstract of Paper before A.S.M.E., Detroit. *Power*, August, 19, 1919; *Railway Review*, August 3, 1919; *Contractor's Record*, August 6, 1919, and *Mechanical Engineering*, August, 1919.

" " . . . . "Using Pulverised Coal as a Boiler Fuel." *Power House*, Vol. 12, 1919.

Harvey, L. C. . . . "Pulverised Coal Systems in America." (117 pages.) Fuel Research Board Special Report No. 1, published by H.M. Stationery Office. 1st Edition, 1919; 2nd Edition, 1922; 3rd Edition, 1923.

" " . . . . "Use of Pulverised Coal." (4000 w.) *Engineering and Industrial Management*, May 15 and 29, 1919.

" " . . . . "Use of Pulverised Coal, with special reference to its Application in Metallurgy." (Serial.) *Colliery Guardian*, May 23, 1919. From Paper before Iron and Steel Institute.

" " . . . . "Pulverised Coal Systems in America." (5000 w.) *Iron and Coal Trades Review*, May 23, 1919.

" " . . . . "Some General Considerations in Regard to the Use of Powdered Coal for Firing Boiler Plants." (2000 w.) *Electrician*, June 27, 1919.

Harvey, L. C. . . . . "New Pulverised Coal Equipment for Railways." *Railway Engineer*, Vol. 41, 1920, pp. 303–7.

,, ,, ... "Use of Pulverised Coal." (12,200 w.) *Engineering*, July 11 and 25, 1919, and August 16, 1919.

,, ,, ... "The Use of Powdered Coal on Railways." (5000 w.) *Railway Gazette*, September 5, 1919.

,, ,, ... "Use of Combustion Instruments and Notes on Pulverised Coal Applications in the Textile Industry." (1000 w.) *The Textile Recorder.*

,, ,, ... "Some Notes on Pulverised Coal Plant." Staffordshire Iron and Steel Institute Meeting. (8000 w.) December 13, 1919.

,, ,, ... "Pulverised Coal." (2200 w.) *Scientific American* (*Supplement*), August 16, 1919. Serial from *Engineering*, London.

,, ,, ... "Pulverised Coal in the Power Station." (3000 w.) *Electrician*, October 1, 1920. (Conclusion of serial.)

,, ,, ... "Pulverised Coal and Colloidal Mixtures." (3000 w.) *Engineering and Industrial Management*, September 15, 1921.

Herington, C. F. . . . "Substituting Powdered Coal for Other Fuels." *Blast Furnace and Steel Plant*, July, 1918.

,, ,, ... *Powdered Coal as a Fuel.* (324 pp.) Published by D. van Nostrand Co., New York, also in *National Engineer*, August, 1918.

,, ,, ... "Pulverised Coal as the Reconstruction Fuel for all Industrial Heating." (2500 w.) *Iron and Steel of Canada*, April, 1919.

,, ,, ... "Powdered Coal as a Fuel." *Western Engineering*, August, 1918.

,, ,, ... "Pulverised Coal in Canadian Steel Plant." *Iron Age*, Vol. 103, 1919.

,, ,, ... "Metallurgical Use of Pulverised Fuel." (2000 w.) *Iron Age*, April 14, 1921.

Herington, C. F., and Wood, W. D. . . . . "Comments on Mr. Arrowwood's Articles." (6500 w.) *Combustion*, October, 1922.

Hood, C. P. . . . . "Trent Process for Cleaning Powdered Coal." (800 w.) *Iron Age*, August 11, 1921.

Howard, M. S. . . . . "A Fireman's Experience with Pulverised Coal." (2000 w.) *Power Plant Engineering*, December 15, 1920.

James, H. . . . . . "Conservation of Fuel." *Power House*, May, 1918.

,, ,, ... "Powdered Fuel." (6000 w.) *Proceedings of South Wales Institute of Engineers*, March 10, May 24, and July 7, 1921.

Johnson, J. B. . . . . "Modern Coal Pulverising Plant at the United Verde." (1500 w.) *Engineering World*, November, 1920.

,, ,, ... "Experience with Powdered Coal in Arizona." (2000 w.) *Electrical World*, December 3, 1921.

June, R. . . . . . "Mechanical Soot Blowers with Coal, Pulverised Fuel and Oil." (2500 w.) *So. Engineer*, January, 1921.

Kentish-Rankin, I. L. . . "Successful Pulverised Coal Installation." *Power Plant Engineering*, Vol. 24, 1920, pp. 313–21.

Kimber, H. A. . . . . "Powdered Coal Advance and Development." (1500 w.) *Blast Furnace and Steel Plant*, January, 1919.

Knowles, E. R. . . . . "Pulverised Fuel." (2500 w.) *Steam*, October and November, 1918.

,, ,, ... "Pulverised Fuel." *Journal American Society of Heating and Ventilating Engineers*, Vol. 26, 1920, pp. 17–72.

,, ,, ... "Pulverised Fuel—Why?" *Combustion*, Vol. 3, 1920, pp. 18–23.

Kreisinger, H., and Anderson, J. . . . . "Powdered Coal for Power Plant Boilers." (900 w.) *Power*, January 4, 1921.

Kreisinger, H., and Blizard, J. "Boiler Test with Pulverised Illinois Coal." (2000 w.) *Mechanical Engineering*, May, 1921. (1800 w.) *Engineering World*, June, 1921; *Coal Industry*, June, 1921, and *Power Plant Engineering*, July 1, 1921.

Lander, C. H. . . . . "Fuel Problem." (7000 w.) *Colliery Guardian*, March 17, 1922; (2000 w.) *Iron and Coal Trades Review*, March 17, 1922. (3000 w.) *Gas Journal*, March 22, 1922; also read before Institute of Mechanical Engineers (South Wales Branch).

Lightfoot, G. . . . . "Coal Economy." *Science and Industry*, September, 1920.

Longnecker, Chas. . . . "Diversified Application of Powdered Coal." *Iron Age*, September 12, 1918.

" " . . . "Pulverised Coal for Metallurgical Furnaces." (500 w.) *Iron Age*, February 6, 1919.

" " . . . "Using Powdered Coal in Forge Furnaces." (1800 w.) *American Drop Forger*, May, 1919.

" " . . . "Using Pulverised Coal for Annealing." *Foundry*, Vol. 47, 1919.

" " . . . "Powdered Coal Winning Out in Special Fields." *Coal Trade Journal*, Vol. 51, 1920, pp. 353–55.

" " . . . "Actual Performance of Powdered Coal." (2000 w.) *Blast Furnace and Steel Plant*, January, 1921.

" " . . . "Experience with Powdered Coal for Heating Furnaces." (1500 w.) *Forging and Heat Treatment*, January, 1921.

" " . . . "Economical Firing of Steel Plant Boilers." (3000 w.) *Blast Furnace and Steel Plant*, May, 1921.

" " . . . "Present Status of Powdered Coal." (2500 w.) *Blast Furnace and Steel Plant*, June, 1921.

Low, F. R. . . . . "Burning Powdered Coal." *Power*, May 10, 1921.

Marble, J. C. . . . . "Colloidal Fuel Applied to Bar Heating Furnaces." (1200 w.) *Engineering*, July 15, 1921.

Marsh, T. A. . . . . "Pulverised Coal Under Boilers." *Electric Railway Journal*, Vol. 55, 1920, pp. 764–65.

Matthew, H. T. . . . . "Burning Powdered Coal in a Rolling Mill." (2200 w.) *Combustion*, April, 1920.

Mathewson, E. P., and Wotherspoon, W. L. . "Application of Pulverised Coal in Blast Furnaces." *Bulletin of Canadian Mining Institute*, July, 1919.

" " . "Pulverised Coal for Blast Furnaces." (3500 w.) *Engineering and Mining Journal*, August 16, 1919.

McAuliffe, J. . . . . "Use of Pulverised Coal in America." (2500 w.) *Commonwealth Engineer*, July 1, 1922.

" " . . . . "Pulverised Coal in the Metallurgical and Cement Industries." (600 w.) *Chemical Engineering and Mining Review*, July 5, 1922.

McIntyre, O. L. . . . . "Pulverised Coal in Metallurgical Furnaces at High Altitudes." *Mining and Metallurgy*, Vol. 162, 1920, pp. 23–26.

Miller, S. . . . . . "Report on Pulverised Fuel by U.S. Fuel and Fuel Handling Committee of Naval Consulting Board." *Journal of American Society of Mechanical Engineers*, May, 1918.

Montgomery, A. L. . . . "Pulverised Fuels." (8500 w.) *Monthly Journal of Chamber of Mines of West Australia*, June 30, 1920.

Muhlfeld, J. E. . . . . "Pulverised Coal in Locomotive and Marine Service." *Mechanical Engineering*, Vol. 41, 1919.

" " . . . . "Use and Abuse of Powdered Fuel for Stationary Boilers." (3000 w.) *Blast Furnace and Steel Plant*, June, 1922.

" " . . . . "Powdered Coal." *Proceedings Engineers' Society of Western Pennsylvania*, Vol. 36, 1920, pp. 243–63.

Muirhead, A. B. . . . . "Development in the Use of Low Grade Fuel at Collieries." *Iron and Coal Trades Review*, Vol. 101, 1920, pp. 33–34.

Odell, W. H. . . . . "Use of Pulverised Coal." (1500 w.) *Steam*, August, 1919.

Ormandy, W. R. . . . "Liquid, Colloidal and Powdered Fuels." (1600 w.) *Engineering*, July 15, 1921. (900 w.) *Colliery Guardian*, July 29, 1921, and *Proceedings of Institute of Mechanical Engineers*, October, 1921.

Orrok, G. A. . . . . "Some Phases of the Fuel Problem." *Steam*, Vol. 24, 1920, p. 21.

Payne, H. M. . . . . "Pulverised Coal at the Bunker Hill and Sullivan Smelter." (1500 w.) *Engineering and Mining Journal*, July 22, 1922.

Perkins, H. C. . . . "Pulverised Fuel Combustion." *Power House*, September, 1918.

Perrott, G. H. J., and Kinney, S. P. . . . . "Trent Process of Cleaning Coal." *American Gas Journal*, August 13, 1921.

Pomeroy, E. E. H. . . "Coal Pulverising Plant at Nevada Consolidated Copper Smelter." *Mining and Metallurgy*, No. 158, 1920.

Powell, E. B. . . . "Pulverised Coal as Power Plant Fuel Past Trial Stage." (1800 w.) *Electrical World*, February 11, 1922.

Prentiss, G. L. . . . "Uses Blow Torch Idea in Furnace." (1200 w.) *Iron Trade Review*, June 9, 1921.

Rau, O. M. . . . "Burning Pulverised Anthracite Mine Waste." (2800 w.) *Electric Railway Journal*, November 26, 1921.

" " . . . . . "Pulverised Fuel for Peak Load Service in Railway Power Plants." *Power*, Vol. 52, 1920, pp. 140–41.

Redmayne, R. A. S. . . "Pulverised Coal as a Combustible." (2000 w.) *Nature*, August 25, 1921.

Reichenbach, H. A. . . "Pulverised Coal Applied to Boilers." (2000 w.) *Cement, Mill and Quarry*, July 20, 1921.

" " . . . "Use of Pulverised Coal in Steam Power Plants." (2000 w.) *Electrical Review*, August 20, 1921.

Renkin, W. O. . . . "Review on the Use of Powdered Coal." (1800 w.) *American Drop Forger*, January, 1919.

" " . . . . "Review on the Use of Powdered Coal." *Blast Furnace and Steel Plant*, February, 1919.

Renkin, W. O., and Longnecker, Chas. . . . "Using Powdered Coal as a Forge Shop Fuel." *American Drop Forger*, Vol. 5, 1919.

Renkin, W. O. . . . "Burning Coal at One Hundred Per Cent. Efficiency." (500 w.) *Gas Age*, November 10, 1920.

" " . . . . "Powdered Coal Means Maximum Efficiency." *Coal Trade Journal*, January 12, 1921.

Rice, C. T. . . . . "Use of Powdered Coal at the Bunker Hill and Sullivan Smelting and Refining Plant." *Engineering and Mining Journal*, July 20, 1918.

Savage, H. D. . . . "Powdered Fuel for Chemical Plants." (1200 w.) *Combustion*, October, 1920. (1000 w.) *Steam*, November, 1920.

" " . . . . "Powdered Coal Efficiencies." *Gas Age*, Vol. 45, 1920, pp. 541–43.

" " . . . . "Use of Powdered Coal under Steam Boilers." (4000 w.) *Iron Age*, June 2, 1921; *American Iron and Steel Institute Advance Paper*, May 27, 1921.

" " . . . . "Powdered Coal." (600 w.) *Steam*, June, 1921.

" " . . . . "Powdered Coal Equipment of Ford Motor Company Plant." (1500 w.) *Canadian Manufacturer*, July 1921.,

" " . . . . "Powdered Coal under Steam Boilers." (1200 w.) *Coal Trade Journal*, September 14, 1921.

" " . . . . "Use of Powdered Coal under Steam Boilers." (1200 w.) *Railway Mechanical Engineer*, September, 1921.

" " . . . . "Application of Pulverised Fuel." (2000 w.) *Combustion*, November, 1921.

Santmeyer, W. J. . . "Powdered Coal." *Electrical Review*, April 18, 1918.

" " . . . . "The Use of Coal in Pulverised Form." *Bulletin of American Institute of Mining Engineers*, No. 143, November, 1918.

Scheffler, F. A. . . . "Some Comments on Pulverised Coal for Power Plants." (2500 w.) *Journal of American Society of Heating and Ventilating Engineers*, January, 1921.

" " . . . . "Pulverised Coal for Boilers." (600 w.) *Combustion*, December, 1921.

" " . . . . "Pulverised Coal for Power Plants." (1200 w.) *Power*, March 15, 1921.

" " . . . . "Higher Steam Pressures or Pulverised Coal ? " (3000 w.) *Journal of American Institute of Electrical Engineers*, May, 1922.

Scheffler, F. A., and Barnhurst, H. G. . . . "Pulverised Coal for Stationary Boilers." (2500 w.) *Power*, August 19, 1919, and *Mechanical Engineering*, August, 1919

Scheffler, F. A., and Barnhurst, H. G. . . . "Pulverised Coal for Boilers." (3000 w.) *Engineering World*, Vol. 15, 1919, pp. 17–22.

Searight, W. H. . . . "Pulverised Coal in tho Steel Plant." (1400 w.) *Blast Furnace and Steel Plant*, August, 1922.

Shagden, J. F. . . . "Industrial Application of Powdered Fuel." (4000 w.) *Iron Age*, March 31, 1921. (3500 w.) *Steam*, May, 1921.

" " . . . "Explosion Hazard and its Prevention." (3000 w.) *Iron Age*, July 21, 1921.

" " . . . "Methods of Preparing Pulverised Coal." *Iron Age*, Vol. 105, 1920, pp. 389–92.

" " . . . "Pulverised Coal Distributing Systems." *Iron Age*, Vol. 105, 1920, pp. 1423–26.

" " . . . "Science of Powdered Fuel Combustion." *Iron Age*, Vol. 106, 1920, pp. 547–61.

" " . . . "Status of the Powdered Fuel Problem." *Iron Age*, Vol. 105, 1920, pp. 32–34.

Shaner, E. L. . . . "Build New Tube Mill in Detroit. Furnaces use Powdered Coal." (3000 w.) *Iron Trade Review*, December 30, 1920.

Shaw, F. S. . . . "Pulverised Fuel." (6500 w.) *Machinery Market*, April 22 and 29, 1921.

Sinnatt, F. S., and Slater, L. "Producer Gas from Pulverised Fuel." (900 w.) *Fuel in Science and Practice*, January, 1922. (1200 w.) *Gas and Oil Power*, March 2, 1922.

St. Perrott, G., and Kinney, S. P. . . . . . "Conditions under which Bulk Oil Concentration of Fine Coal gives Best Results." (2700 w.) *Coal Age*, August 4, 1921.

Taylor, H. S. . . . "Fuel Production and Utilisation." Reference to Powdered Fuel, pp. 62–87. Published by Baillière, Tindall and Cox, 8, Henrietta Street, Covent Garden.

Thompson, P. W. . . "Pulverised Fuel at Oneida Street Plant." *Power*, Vol. 51, 1920, pp. 339–40.

Tracy, L. D. . . . "How to Protect Pulverised Coal Plants from Dust Explosions and Fires." (4500 W.) *Coal Age*, April 28, 1921.

" " . . . "Explosion Hazards in Using Pulverised Coal." (2200 w.) *Forging and Heat Treatment*, May, 1921.

" " . . . "Coal Dust Hazards in Industrial Plants." (2500 w.) *Universal Engineer*, June, 1921.

" " . . . "Fire Hazards in Plants Using Pulverised Coal." (5500 w.) *Blast Furnace and Steel Plant*, July, 1922; *Power*, June 27, 1922.

" " . . . "Pulverised Coal is Dangerous on the Surface as well as Underground: Precautions to be taken in Handling it." (3300 w.) *Coal Age*, August 3, 1922.

Trinks, W. . . . . "Heating Furnaces and Annealing Furnaces." *Blast Furnace and Steel Plant*, Vol. 8, 1920, pp. 288–89.

Welles, E. R., and Jacobi, W. H. . . . . "Powdered Coal as a Fuel for Boilers." (4500 w.) *Steam*, September, 1920; (2200 w.) *Steam*, October, 1920; *Stevens Indicator*, Vol. 37, 1920, pp. 97–125.

Wilcox, W. G. . . . "Use of Powdered Coal." *Mining and Scientific Press*, June 22, 1918; *Western Engineering*, July, 1918.

" " . . . "The Possibilities of Powdered Coal." *Scientific and American Supplement*, July 27, 1918.

" " . . . "The Possibilities of Powdered Coal as shown by its Combustion Characteristics." *Chemical and Metallurgical Engineering*, July 1, 1918; *Steam*, September, 1922.

" " . . . "Control of Combustible and Air in Burning Powdered Coal." *Compressed Air Magazine*, August, 1918. (1500 w.) *Colliery Guardian*, October, 1918.

" " . . . "Suggestions for Burning Pulverised Coal." (2500 w.) *American Drop Forger*, December, 1918.

" " . . . "The Possibilities of Powdered Coal." (1000 w.) *Colliery Guardian*, December 6, 1918. (300 w.) *Colliery Guardian*, December 27, 1918.

" " . . . "Characteristics of Powdered Coal." (4500 w.) *Brick and Clay Recorder*, January 28, 1919.

Wilcox, W. G. . . . . "Burning Pulverised Coal." (2200 w.) *Compressed Air Magazine*, February, 1919.

" " . . . . "Success in Combustion of Powdered Coal." (2500 w.) *Black Diamond*, March 22, 1919.

" " . . . . "Burning Powdered Coal—the Carburisation System." (850 w.) *Engineering World*, July 15, 1920; (1320 w.) *Cement, Mill and Quarry*, July 20, 1920.

Wood, W. D. . . . . "Pulverised Lignite as Locomotive Fuel." (400 w.) *Railway Mechanical Engineer*, August, 1921.

Wotherspoon, W. L. . . "Pulverised Coal in Blast Furnaces." (800 w.) *Canadian Mining Journal*, February 5, 1919.

PULVERISED COAL.

Articles in the Continental Press (Period 1918–1922).

Editorial.

"Nuevo Metodo para Quemar Carbon Pulverizado." (890 w.) *Boletin de la Sociedad de Fomento Fabril*, Vol. 35, September, 1918, pp. 639–40.

"Carbon Pulverizado para Calderas Fijas." (3500 w.) *Boletin de la Sociedad de Fomento Fabril*, June, 1920.

"Le Chauffage au Charbon Pulvérisé." *Bulletin Société d'Encouragement*, Vol. 133, May, 1921, pp. 478–507.

"L'Emploi du Charbon Pulvérisé aux Mines de Blanzy." (600 w.) *Echo des Mines*, January 20, 1922.

"L'Impiego dei Combustibile Solidi Polverizzato." (4500 w.) *Elettricita*, April 30, 1921.

"Einiges über die Verfeuerung Gemahlener Kohle." (1500 w.) *Elektrotech. Anzeiger*, April 14, 1921.

"Locomotive Chauffée au Charbon Pulvérisé du Great Central Railway (Angleterre)." (1240 w.) *Genie Civil*, June 21, 1919.

"L'Emploi du Charbon Pulvérisé pour le Chauffage des Fours et des Chaudières." (3000 w.) *Génie Civil*, May 28, 1921.

"L'Entraînement des Combustibles Pulvérisés par un Courant d'Air." (800 w.) *Génie Civil*, July 8, 1922.

"L'Emploi du Charbon Pulvérisé aux Usines Siderurgiques de la Knoxville Iron Co. (Tennessee, E.U.)." (1800 w.) *Génie Civil*, October 8, 1921.

"Appareil 'Atritor' pour la Préparation du Charbon Pulvérisé." (1000 w.) *Génie Civil*, September 9, 1922.

"Le Chauffage Industriel par le Charbon Pulvérisé." *Industrie Electrique*, Année 29, 1920, pp. 236–37.

"El Carbon Pulverizado en las Fabricas Pequeñas." (1500 w.) *Ingeniero Internacional*, Vol. 7, March, 1922, pp. 154–55.

"Kohlenstaubfeuerung in der Metall-Industrie." (2500 w.) *Metall*, March 25, 1920.

"Die Herstellung des Kohlenstaubes für Staubfeuerung." (2800 w.) *Mittäg. Zeit. für Dampfkessel u. Maschinenbetrieb*, April 29, May 13 and 20, 1921.

"Die Herstellung des Kohlenstaubes für Staubfeuerung." (700 w.) *Mittäg. Zeit. für Dampfkessel u. Maschinenbetrieb*, May 6, 1921.

"L'Application du Charbon Pulvérisé aux Locomotives." (2500 w.) *Outillage*, January 27, 1921.

"Il Combustible Polverizzato." (1500 w.) *Rassegna Mineraria*, February 28, 1922.

"Les Economies de Combustible Obtenues par l'Emploi du Charbon Pulvérisé." *Revue Générale de l'Electrique*, June 29, 1918.

"Commission d'Utilisation du Combustible." (3500 w.) *Revue Industrie Minérale*, August 1, 1921.

"El Empleo del Carbon Pulverizado en las Fabricas." *Revista de Obras Publicas*, April, 1918, pp. 174–75.

"Economia del Combustible per Impiego di Carbone Polverizzato." *Revista Tecnica d'Elettricina*, 1919, pp. 11–16.

"Der Kohlenstaub, seine Herstellung im Grossen und seine Verfeuerung." (3500 w.) *Tech. Blätter*, May 13, 1922.

"Utilisation du Combustible Pulvérisé dans les Foyers des Locomotives." *La Technique Moderne*, Annee 12, No. 12, February, 1920.

PULVERISED COAL.

Articles in the Continental Press (Period 1918–1922).

Authors.

Audibert, M. E. . . . . "Etude de l'Entraînement du Poussier de Houille par l'Air." (2500 w.) *Revue Industrie Minérale*, January 1, 1922; *Annales des Mines*, No. 1, 1922.

Balley, K. M. . . . . "Ein neues Verfahren zur Staubkohlenvergasung." (1000 w.) *Chemik. Zeitung*, August 18, 1921.

Bansen, H. . . . . "Die Kohlenstaubfeuerung in Amerika." (5000 w.) *Stahl und Eisen*, September 16, 1920.

Baron, G. . . . . "Le Combustible Pulvérisé." (1200 w.) *Memoires Société Ingénieurs Civils*, July and September, 1921.

Bassani, G. . . . . "Il Carbone Polverizzato." (3000 w.) *Industria* (Milan), January 31, 1921.

Birkner . . . . . "Die Braunkohlenstaubfeuerung Walter-Farner-Decker-Berg." *Braunkohle*, May 6, 1922.

" . . . . . "Ueber Kohlenstaubfeuerung." (2500 w.) *Wärme*, April 21, 1922.

Bousquet, M. . . . . "Le Chauffage Industriel par le Charbon Pulvérisé." *Nature*, 1919, pp. 318–20.

Bulle, G. . . . . "Anwendbarkeit der Kohlenstaubfeuerung in Eisenhüttenwerken." (5000 w.) *Stahl und Eisen*, July 21, 1921.

Bulle, M. . . . . "Quelques Considérations sur l'Emploi du Charbon Pulvérisé." (2500 w.) *Chaleur et Industrie*, Vol. 2, April, 1921, pp. 184–88.

Damour, E. . . . . "Progrès Realizé Pendant la Guerre dans l'Utilisation des Combustibles." *Industrie Electrique*, January 10, 1919.

Dick, A. H. . . . . "Uso del Carbon Pulverizado en el Brasil." (2500 w.) *Ingeniero Internacional*, Vol. 8, October, 1922.

Fournick, M. . . . . "Le Chauffage Industriel par le Charbon Pulvérisé." *Revue Générale des Sciences*, 1920, pp. 112–21.

Franco, I. . . . . "Het Stoken met Kolenpoeder." *Ingenieur*, November 5, 1921.

Frion, P. . . . . "Le Chauffage au Charbon Pulvérisé." *Annales des Mines*, Vol. 1, pt. 2, 1922, pp. 100–148; *Chaleur et Industrie*, May, June and July, 1921.

Frion, P. . . . . "Le Chauffage Industriel au Charbon Pulvérisé." (8000 w.) *Revue Générale Electrique*, June 4, 1921. (6500 w.) June 11, 1921.

" . . . . . "Le Chauffage au Charbon Pulvérisé." *Memoires Société Ingénieurs Civils*, April–June, 1921.

Gentine, H. L. . . . . "Combustible Atomizado." (1600 w.) *Ingeniero Internacional*, Vol. 6, August, 1921, pp. 114–15.

Gilard, P. . . . . "Chauffage au Charbon Pulvérisé." (3000 w.) *Revue Universelle des Mines*, October 1, 1921.

Helbig, A. B. . . . . "Die Gefahren des Brennstaubes." (2000 w.) *Feuerungstechnik*, June 1, 1922.

" " . . . . "Die Vermahlung der Brennstoffe." (4000 w.) *Feuerungstechnik*, March 1, and April 1, 1922.

" " . . . . "Staubverbrennung." (2000 w.) *Feuerungstechnik*, July 1, 1922.

Hermanns, H. . . . . "Beitrag zur Frage der Verfeuerung von Kohlenstaub." (1000 w.) *Wärme*, May 19, 1922.

Jaramillo, R. . . . . "Combustibles usados en las Industrias y Especialmente en Locomotoras." *An. Inst. Ingenieros* (Chile), May, June and July, 1920.

Kaiser, F. . . . . "Versuche mit einer Kohlenstaubfeuerung." (4700 w.) *Ztsch. Bayer. Revisions-Vereins*, July 31, and August 15, 1922.

Kalpers, H. . . . . " Kohlenstaubfeuerung in einer Amerikanischen Dampfkesselbatterie." (1500 w.) *Ztsch. Ges. Giessereipraxis,* July 30, 1921.

Lasseur, E. . . . . " L'Emploi du Charbon Pulvérisé sur les Locomotives." *Génie Civil,* Vol. 74, 1919.

Maisonneuve, M. . . . " L'Etat Actuel du Chauffage au Charbon Pulvérisé." (2500 w.) *Outillage,* April 21, 1921.

Matthiass . . . . . " Der Kohlenstaub, seine Herstellung in Grossen und seine Verfeuerung." (1000 w.) *Tech. Blätter,* April 21, 1922.

Montanes, C. E. . . . " Carbon Pulverizado." (3000 w.) *Rev. Obras Pub.,* August 19, 1920.

Perrot, St. J., and Kinney, S. P. . . . . . " Limpieza del Carbon por Medio del Petroleo." (5000 w.) *Ingeneiro Internacional,* Vol. 6, November, 1921, pp. 282–87.

Pradel . . . . . " Die Verfeuerung von Kohlenschlamm mit 26.1 v. H. Wasser auf dem Plutorost." (700 w.) *Tech. Blätter,* February 11, 1922.

,, ... " Kohlenstaubfeuerung für Hochleistungskessel." (3500 w.) *Elektrotech. Anzeiger,* July 12 and 13, 1921.

,, ... " Staubfeuerungen zur Dampferzeugung." (4000 w.) *Zeitschr. für Dampfkessel u. Maschinenbetrieb,* June 17, 1921.

Radiguer, D. . . . . " Les Foyers de Chaudières. Grilles Mécaniques et Charbon Pulvérisé." (14,000 w.) *Revue Industrielle,* May, June, September and October, 1922.

Reveillac, M. . . . . " L'Emploi du Charbon Pulvérisé." *Bulletin et Comptes Rendus Mensuels de la Société de l'Industrie Minérale,* Vol. 16, 1919, pp. 347–65.

Richarz, H. . . . . " Allgemeines über Staubkohlenfeuerung." (2500 w.) *Zeitschrift für Dampfkessel und Maschinenbetrieb,* April 15, 1921.

Robinson, J. G. . . . " Perfectionnements dans l'Emploi de Combustible Pulvérisé dans les Foyers de Générateurs de Vapeur." *Bulletin Officiel de la Propriété Industrielle et Commerciale,* No. 1774, 1918, p. 7.

Schendorff, H. . . . " Four à Souder Chauffé au Charbon Pulvérisé au Moyen d'un ' Aero ' Pulvériseur." *Technique Moderne,* Anne 12, 1920, pp. 81–2.

Schulte, F. . . . . " Die Kohlenstaubfeuerung für Dampfkessel." (4500 w.) *Glückauf,* April 30, 1921.

Sohm, M. . . . . . " Chauffage des Chaudières au Charbon Pulvérisé." *Revue Industrielle Minérale,* September 15, 1922.

Venancourt, G. de . . " Utilisation du Charbon Pulvérisé au Chauffage des Fours à Cuivre." *Revue de Metallurgie,* Année 17, 1920, pp. 2–12.

Weiss, M. . . . . . " Unmittelbare Trocknung der Rohbraunkohle mittels Feuergasen und Verheizung der getrockneten Kohle in Staubform." (1500 w.) *Tech. Blätter,* May 6, 1922.

,, ... " Braunkohlen Trocknung und Staubfeuerung." (3500 w.) *Braunkohle,* May 6, 1922.

Weiss, M., and Haering . " Die Aufbereitung Rheinischer Braunkohle zu Staub (nach dem Verfahren der Buttner-Werke, A. G., Verdingen a. Rh.) und die Verwendung des Staubes zur Beheizung eines Blockwärmeofens." (2500 w.) *Braunkohle,* January 7, 1922.

PULVERISED COAL.

Articles in the English, American and Continental Press (Previous to 1918).

Editorial.

" Coal Pulveriser and Automatic Stoker." *American Electrician,* Vol. 14, pp. 196–97.

" Pulverised Coal Burning in Chicago." *American Electrician,* Vol. 14, pp. 13–14.

"System of Burning Coal Dust." *American Miller*, Vol. 30, 1902, p. 1006.

"Notes sur les Dangers que Paraît Présenter la Poussière de Houille dans les Mines, Mêmo en l'Absence de Grison." *Annales des Mines, Memoires*, Vol. 7, ser. 7, 1875, pp. 176–79.

"Pulverised Coal as a Cheap Fuel." *Automobile*, June 5, 1913. Letter.

"Kohlenstaubfeuerung im Dampfkesselhause des Koeniglichen Opernhauses in Berlin (Patent Ruhl)." *Centralblatt der Bauverwaltung*, Vol. 16, 1896, p. 59.

"Novelties in Coal-Dust Firing Apparatus." *Colliery Guardian*, Vol. 76, 1898, p. 514. Abstract from *Tonindustrie Zeitung*.

"The Utilisation of Coal Sludge and Coal Dust." *Colliery Guardian*, Vol. 77, 1899, p. 477. Abstract from *Neues Saarbrueckener Gewerbeblatt*.

"Versuche mit den Kohlenstaubfeuerungen von Schwartzkopff und Friedeberg." *Dampf*, Vol. 13, 1896, p. 710.

"Staubkohlenfeuerung (Einrichtung und Versuche in der Inkrustasteinfabrik zu Poetzensee)." *Dampf*, Vol. 11, 1894, p. 102.

"Ueber Kohlenstaubfeuerungen." *Dampf*, Vol. 11, 1894, p. 509.

"Neuerungen an Kohlenstaubfeuerungen." *Dingler's Polytechnische Journal*, Vol. 305, 1897, pp. 189–90.

"Neuere Dampfkessel Kesselfeuerungen." *Dingler's Polytechnische Journal*, Vol. 291, 1894, pp. 241–47.

"Ueber Kohlenstaubfeuerungen." *Dingler's Polytechnische Journal*, Vol. 292, 1894, pp. 265–70.

"Neuere Kesselfeuerungen." *Dingler's Polytechnische Journal*, Vol. 287, 1893, p. 108.

"Kohlenstaubfeuerung von Baumert und Wegener." *Dingler's Polytechnische Journal*, Vol. 289, 1893, p. 23.

"Coal Dust Firing for Steam Boilers." *Engineer*, Vol. 99, 1905, pp. 502–3.

"Tests of Pulverised Fuel." *Engineer* (U.S.), Vol. 41, 1904, pp. 259–60.

"Pulverised Fuel." *Engineer* (U.S.), Vol. 40, 1903, pp. 272–75.

"Improved System of Burning Coal Dust." *Engineer* (U.S.), Vol. 40, 1903, pp. 93–94.

"Berlin Industrial Exhibition." *Engineer*, Vol. 82, 1896, p. 255.

"Wegener's Powdered Fuel Boiler Furnace and Apparatus." *Engineer*, Vol. 81, 1896, pp. 485–86.

"Coal Dust Fuel." *Engineer*, Vol. 43, 1877, pp. 335–36.

"Ruehe's Apparatus for Burning Powdered Coal." *Engineering*, Vol. 63, 1897, p. 72.

"Combustion of Powdered Coal." *Engineering*, Vol. 61, 1896, pp. 80–81.

"A Rotary Brush System of Feeding Pulverised Fuel to Furnaces." *Engineering News*, Vol. 47, 1902, p. 147.

"A New System for Burning Powdered Coal." *Engineering News*, Vol. 48, p. 548, 1902.

"Powdered Fuel for Boiler Furnaces at the Alpha Cement Company's Works, Alpha, N.J." *Engineering News*, Vol. 45, 1901, pp. 542–43.

"A New Method of Burning Powdered Fuel." *Engineering News*, Vol. 45, 1901, pp. 178–79.

"Two Recent Systems for Burning Powdered Fuel." *Engineering News*, Vol. 46, 1901, pp. 415–16.

"Burning Powdered Coal under Steam Boilers." *Engineering News*, Vol. 38, 1897, pp. 189–90.

"Powdered Anthracite and Gas Fuel." *Engineering News*, Vol. 16, 1896, pp. 314–15.

"The Utilisation of Coal Dust as Fuel." *Engineering News*, Vol. 10, 1883, p. 163.

"Comparative Boiler Tests with Ordinary and Pulverised Coal Firing." *Engineering Record*, Vol. 49, 1904, p. 342.

"Buffalo Grain Elevator Dust Explosion." *Engineering News*, July 31, 1913. Reprinted in *National Fire Protection Association Quarterly*, October, 1913.

"The Rowe System of Burning Pulverised Coal." *Engineering Record*, Vol. 46, 1902, p. 592.

"The Aero System of Pulverised Fuel Combustion." *Engineering Record*, Vol. 43, 1901, p. 506.

"Burning Powdered Coal in Stationary Boilers." *Engineering Record*, Vol. 42, 1900, pp. 615–16.

"Burning of Pulverised Coal." *Engineering Record*, Vol. 42, 1900, pp. 241–42.

"Freitag's Kohlenstaub." *Feuerung, Kraft*, Vol. 17, 1900, pp. 5–6.

"Ueber den Gegenwaertigen Stand der Kohlenstaubfeuerung, Haeussermann." *Gewerblich Technischer Ratgeber*, Vol. 1, 1902, pp. 227–29.

"Kohlenstaubfeuerung nach System Cornelius (Deutsches Reichs-Patent 78, 587)." *Glaser's Annalen für Gewerbe und Bauwesen*, Vol. 39, 1896, pp. 139–40.

"Coal Dust Fired Boiler." *Indian Engineering*, November 29, 1913.

"Powdered Coal as Fuel." *Indian Engineering*, August 16, 1913.
"Apparatus for Burning Coal Dust (Friedeberg System)." *Industries and Iron*, Vol. 17, 1894, p. 354.
"Friedeberg Apparatus for Burning Coal Dust." *Industries and Iron*, Vol. 17, 1894, p. 405.
"Burning Coal Dust without Smoke." *Iron Age*, November 6, 1902.
"Improved Pulverised Fuel Feed Device." *Iron Age*, November 6, 1913.
"Powdered Coal for Open-Hearth Furnaces." *Iron Age*, October 16, 1913.
"New Iron Mill Equipped to Assure Low Costs." *Iron Age*, July 8, 1915.
"Regenerators for Open-Hearth Powdered Coal Fired Furnaces." *Iron Age*, May 18, 1916.
"Powdered Coal Burning at Works of Standard Steel Car Company, Middletown, Pa." *Iron Age*, July 20, 1916.
"Coal Dust Firing as Applied to Annealing Furnaces." *Iron and Coal Trades Review*, Vol. 70, 1905, p. 1999.
"New Coal Dust Furnaces." *Iron and Coal Trades Review*, Vol. 47, 1898, pp. 177–78.
"Powdered Coal for Large Furnaces." *Iron Trade Review*, April 26, 1917.
"Kesselfeuerung mit Pulverisierter Kohle." *Leipziger Monatsschrift für Textil Industrie*, Vol. 17, 1902, p. 479.
"Powdered Coal as Fuel." *Marine Engineer*, Vol. 17, 1896, p. 433.
"Utilising the Waste from Coal Mines in the Pacific North-West." *Metallurgical and Chemical Engineering*, May 15, 1917.
"Powdered Coal Plant in Anaconda." *Metallurgical and Chemical Engineering*, May, 1915.
"Progress in Fuel Utilisation." *Mining and Scientific Press*, October 25, 1913.
"Rauchlose Kohlenverbrennung (Mittelst Staubkohle)." *Mittheilungen aus dem Gebiete des Seewesens*, Vol. 21, 1893, p. 63.
"Ueber Verwerthung von Kohlenschlamm und Kohlenstaub." *Oest. Zeitschrift für Berg und Hüttenwesen*, Vol. 57, 1899, pp. 127–29.
"Kohlenstaubfeuerungen von Schwartzkopff." *Oest. Zeitschrift für Berg und Hüttenwesen*, Vol. 43, 1895, pp. 187–88.
"Using Soft Coal Screenings." *Power*, Vol. 29, 1908, p. 706.
"Burning Powdered Coal under Boilers." *Power*, Vol. 23, 1903, pp. 434–47.
"Pulverised Fuel for Power Plants." *Railroad Gazette*, Vol. 24, 1902, pp. 13–14.
"Pulverised Coal Plant for the Santa Fé Railway." *Railway Age Gazette*, February 9, 1917.
"Railway Fire Protection Association, St. Louis, October 2, 4." *Railway Age Gazette*, October 19, 1917.
"Burning Pulverised Coal." *Railway and Engineering Review*, Vol. 40, 1900, pp. 560–62.
"Bettington Boilers for Pulverised Fuel." *Railway News*, Vol. 96, 1911, pp. 1422–23.
"Chauffage des Chaudières au Charbon Pulvérisé (Système F. Frost)." *Revue Industrielle*, Vol. 29, 1898, p. 16.
"Chauffage des Chaudières au Charbon Pulvérisé (Système Baumert et Wegener)." *Revue Industrielle*, Vol. 25, 1894, pp. 641–62.
"Foyers du Système de MM. Baumert et Wegener pour l'Utilisation sous les Chaudières de Charbon Pulvérisé." *Revue Universelle des Mines*, Vol. 24, 1893, pp. 238–41.
"Kohlenstaubfeuerungen." *Ruhl. Kraft*, Vol. 18, pt. 1, 1901, pp. 35–37.
"Kohlenstaubfeuerungen (Zusammenstellung der Verschiedenen Erfindungen und Patente)." *Schweizerische Bauzeitung*, Vol. 34, 1899, pp. 4–6.
"Pulverised Coal an Economical Steam Fuel." *Steam*, May, 1912, pp. 135–38.
"Kohlenstaubfeuerung (System Unger)." *Tonindustrie Zeit.*, Vol. 20, 1896, p. 861.
"Kombinierte Kohlenstaubfeuerung." *Zeitschrift für Beleuchtungswesen*, Vol. 7, 1901, pp. 332–33.
"Versuchsergebnisse mit der Wegner'schen Kohlenstaubfeuerung." *Zeit. Verband Dampfkessel Ueberwach. Ver.*, Vol. 18, 1895, p. 380.
"Kohlenstaubfeuerungen." *Zeit. des Vereines deutscher Ingenieure*, Vol. 40, 1896, pp. 432, 436.
"Kohlenstaubfeuerungen." *Zeit. des Vereines deutscher Ingenieure*, Vol. 39, 1895, pp. 1379–82. Abstract in *Engineer*, Vol. 81, 1896, p. 106.
"Powdered Coal." *Reports of Commission to International Railway Fuel Association*, 1915, 1916, 1917. Conventions.

PULVERISED COAL.

Articles, Books and Pamphlets in the English, American and Continental Press (Previous to 1918).

Authors.

Anderson, William . . "Perrot's Furnace for Dust Fuel." *Iron Age*, December 10, 1895, pp. 643–56.

Barnhurst, H. G. . . "Wider Utilisation of Pulverised Coal." *Iron Age*, October 23, 1913, pp. 906–8.

" " . . "Pulverised Coal as a Fuel." *Metallurgical and Chemical Engineering*, March, 1913, pp. 127–29.

" " . . "Use of Pulverised Coal as Fuel for Metallurgical Furnaces." *Bulletin of the American Institute of Mining Engineers*, October, 1913, pp. 2523–32. Discussion, December, 1913, pp. 2856–63.

" " . . "Powdered Fuel Installation Service 10–250 Horse-Power O'Brien Boilers." *Journal of American Society of Mechanical Engineers*, October, 1916.

" " . . "General Utilisation of Pulverised Coal." December, 1917.

Barr, William M. . . "A Practical Treatise on the Combustion of Coal, etc." Book Published by Yohn Bros., Indianapolis, 1879.

Bartlett, C. O. . . . "Burning of Pulverised Coal." *Association of Engineering Societies Journal*, 1903, pp. 44–48; *Railway and Engineering Review*, Vol. 43, 1903, pp. 568–69; *Engineer* (U.S.), Vol. 50, 1903, pp. 563–64.

Bean, W. R. . . . "Pulverised Coal for Air Furnaces." *Iron Trade Review*, September 27, 1917.

Beistle, C. P. . . . "Hazards in the Storage of Pulverised Coal."

Bender, Louis, V. . . "Coal-Dust Fired Reverberatories at Washoe Reduction Works." *Bulletin of the American Institute of Mining Engineers*, January, 1915, and May, 1915, pp. 73 and 1174 (respectively).

Blakemore, W. . . . "Economic Value of Coal Dust." *Canadian Mining Review*, 1896, pp. 200–1.

Bleichsteiner, Ferdinand . "Kohlenstaubfeurerungen." *Oest. Zeitschrift für Berg und Hüttenwesen*, Vol. 44, 1896, pp. 237–40.

Boby, William . . . "Meldrum Self-Contained Dust-Fuel Furnace." *Federated Institution of Mining Engineers, Trans.*, Vol. 3, 1891–92, pp. 250–55.

Browne, David H. . . "Recent Improvements and Additions to the Smelting Plant of the Canadian Copper Company." *Canadian Mining Institute, Trans.*, Vol. 15, 1912, pp. 115–22.

" " . . "Coal-Dust Fired Reverberatory Furnaces at Canadian Copper Company." *Bulletin of the American Institute of Mining Engineers*, January, 1915, p. 49.

" " . . "Firing of Reverberatory Furnaces with Pulverised Coal." *Transactions of the Canadian Mining Institute*, Vol. 15, p. 115.

Bryan, William H. . . "Problem of Smoke Abatement." *American Machinist*, Vol. 29, pt. 2, 1906, pp. 52–54.

Bunnell, Sterling H. . . "Problem of Burning Pulverised Coal." *Iron Age*, September 18, 1913, p. 618.

Caracristi, V. Z. . . . "Utilisation of Waste and Undeveloped Fuels in Pulverised Form." Pts. I and II. *General Electric Review*, September, 1917.

" " . . . "The Use of Pulverised Fuel for Locomotive Operation." *General Electric Review*, November, 1917.

" " . . . "Use of Coal Dust as Fuel for Boilers." *Iron and Coal Trades Review*, Vol. 58, 1899, p. 643.

Carey, Eustace . . . "Firing with Coal Dust." *Society of Chemical Industry Journal*, Vol. 24, pp. 369–71; discussion, pp. 371–72, 1905. Abstract in *Engineering and Mining Journal*, Vol. 80, 1905, pp. 1113–14.

Carpenter, R. C. . . . "Use of Pulverised Coal as a Fuel for Boilers." *Sibley Journal of Engineering*, December, 1913, p. 85.

" " . . . . "Symposium on Powdered Fuel." *The American Society of Mechanical Engineers*, June, 1914. Extracts of Papers by various Authors.

Cederblom, R. . . . "Feeding Pulverised Coal to Furnaces." *Power*, Vol. 28, 1908, pp. 299–300.

Chevillard, P. . . . "Chauffage des Chaudières au Charbon Pulvérisé." *Revue Industrielle*, Vol. 28, 1897, pp. 162, 294, 385.

Clark, D. Kinnear (Editor) . "Fuel: Its Combustion and Economy." Crosby, Lockwood, 1879.

Coffin, E. P. . . . "The Use of Low Grade Universal Fuels and the Status of Powdered Coal." *General Electric Review*, August, 1917.

Collins, H. R., and Harrington, Joseph . . . "Pulverised Fuel in a Power Plant on the Missouri, Kansas and Texas Railway." *General Electric Review*, October, 1917.

Colomer . . . . "Apparatus para la Combustion de Carbones Menudos." *Revista Minera*, Vol. 45, 1895, p. 175.

Crampton, T. R. . . "On the Combustion of Powdered Fuel in Revolving Furnaces and its Application to Heating and Puddling Furnaces." *Iron and Steel Institute Journal*, 1873, pp. 91–101; discussion, pp. 101–107.

Damour, Emilio, and Queneau, A. L. J. . . . "Industrial Furnaces." *New York Engineering and Mining Journal*, 1906, pp. 275–86.

Davis, H. V. Hart . . "Dust Fuel Boiler and its Uses." *Manchester Geological and Mining Society, Trans.*, Vol. 22, 1912, pp. 224–33; discussion, pp. 223–42. Abstract in *Iron and Coal Trades Review*, February 23, 1912, pp. 198–299; *Engineering Magazine*, March, 1913, pp. 936–38.

Donkin, Bryan . . . "Steam Boilers with Forced Blast: The Perret System for Burning Dust and Rejected Fuels with Notes on Testing Boilers." *Federated Institution of Mining Engineers, Trans.*, Vol. 4, 1892–93. Discussion of Papers, pp. 348–50.

Douglas, R. A. . . . "Pulverised Fuel." *American Electrician*, Vol. 13, 1901, pp. 434–35.

Dutton, Lieut. C. E. . . "On the Use of Pulverised Fuel." *Franklin Institute Journal*, Vol. 81, p. 377; Vol. 92, p. 17, 1871.

Durand, F. W. . . . "Progress and Outlook in Prime Movers." *Electrical World*, January 6, 1917.

Ennis, Wm. D. . . . "Pulverised Coal, a New Fuel." *Automobile*, Vol. 25, 1911, pp. 620–21.

" " . . . . "Some Industrial Applications of Pulverised Coal." *Brooklyn Engineers' Club, Proc.*, Vol. 12, 1908, pp. 183–200; discussion, pp. 201–17.

" " . . . . "Pulverised Coal and Its Industrial Applications." *Engineering Magazine*, Vol. 34, 1907–1908, pp. 463, 577.

Forster . . . . "Kohlenstaubfeuerungen." *Uhlands Technische Rundschau*, No. 3, 1896, p. 24.

Fowler, Wm. B. . . . "Steam Boilers and Supplementary Appliances." Manchester Scientific Publishing Co., pp. 491–92.

Friedrich . . . . "Herstellung von Kohlenstaub für Kohlenstaubfeuerungen." *Dampf*, Vol. 13, 1896, p. 710.

Fuller, J. W. . . . "Pulverised Coal for Open-Hearth Furnaces." *Iron Trade Review*, November 2, 1916.

Gadd, C. J. . . . "The Use of Powdered Coal in Metallurgical Processes: A Discussion of the Engineering Principles Involved." *Journal of the Franklin Institute*, September, 1916, p. 323.

" " . . . . "Utilising Powdered Coal at Lebanon, Pa." *Iron Age*.

Gasche . . . . "Pulverised Fuel for Power Plants." (Aero Pulveriser). *Railway Gazette*, Vol. 34, 1902, pp. 446–67.

Glaser, L. . . . . "Ueber Eine Neue Feuerung (Patent Kudlicz) Zum Verbrennen von Kleinkohle, Kohlenloesche, Schlammkohle, Koksklein, Braunkohlenabfaellen und Dergl." *Glaser's Annalen für Gewerbe und Bauwesen*, Vol. 33, 1893, pp. 31–37.

Goodrich, W. Francis . . "Utilisation of Low-Grade Fuels for Steam Generation." *Engineering Magazine*, Vol. 30, 1905, pp. 346–54.

Groves, Charles Edward, and Thorp, William. "Fuel and Its Applications." By E. J. Mills and F. R. Rowan, Philadelphia, Bladiston, 1889, pp. 364, 664.

Hachtmann, A. P. . . "Pulverised Coal *versus* Producer Gas as a Fuel for Nodulising Fine Ore in the Rotary Kiln." *Chemical Engineer*, May, 1909.

Halleux, A. . . . "Emploi du Charbon Pulvérisé dans les Foyers des Chaudières et des Fours Métallurgiques (système Schwartzkopff)." *Revue Universelle des Mines*, Vol. 46, 1899, pp. 21–34.

Harrison, W. R. . . . "Dust Fuel Stokers and Auxiliary Plant." Leeds University Society, December 10, 1906.

" S. H. . . . "Pulverised Coal: Its Preparation and Use in Industrial Furnaces." *Engineering Magazine*, February, 1916.

Harrington, Joseph . . "Powdered Coal as a Fuel in Malleable Shops." *Foundry*, September, 1916, October, 1916, December 1916, and January, 1917.

" " . . "The Use of Powdered Coal as a Fuel." *Journal of American Society of Mechanical Engineers*, October, 1916.

Herington, C. F. . . . "Powdered Coal for Heating Furnaces." *Iron Age*, November 5, 1914.

" " . . . . "New System of Burning Powdered Coal." *Engineering News*, May 27, 1915.

" " . . . . "Comparison of the Economy of Powdered Coal, Oil and Water Gas for Heating Furnaces." *Engineering News*, December 10, 1914.

Hitchcock, E. A. . . "Road Tests of Brooks Passenger Locomotives." *American Society of Mechanical Engineers, Trans.*, Vol. 26, 1905, pp. 290–306; discussion, pp. 306–11.

Hofman, H. O. . . . "General Metallurgy." New York, McGraw-Hill Book Co., 1913, pp. 183–89.

Hughes, L. S. . . . "Combustion of Pulverised Coal." *American Institute of Chemical Engineers, Trans.*, Vol. 4, 1911, pp. 347–49.

Hutton, Frederick Remsen . "The Mechanical Engineering of Steam Power Plants." 3rd Edition, New York, Wiley, 1908.

Isherwood, B. F. . . "On the Use of Pulverised Fuel." *Engineering and Mining Journal*, Vol. 21, 1876, pp. 12, 31, 57, 104, 129.

Izart, J. . . . . "De l'Emploi des Poussiers dans les Foyers Méchaniques." *L'Electricien*, Vol. 41, 1911, pp. 54–57.

Kaufmann, L. . . . "Die Freitagsche Kohlenstaubfeuerung." *Zeitschrift des Vereines deutscher Ingenieure*, Vol. 43, 1899, pp. 988–92.

" " . . . . "Freitag Apparatus for Coal Dust Fuel." *Colliery Guardian*, Vol. 78, 1899, pp. 542–43. Abstract of article in *Zeitschrift des Vereines deutscher Ingenieure.*

Kavanagh, Wm. . . . "Methods of Burning Anthracite Coal Dust." *Electrical World*, December 7, 1912.

Kent, Wm. . . . "Steam Boiler Economy." New York, Wiley, 1901, p. 183.

Kinyon, Alonzo . . . "Powdered Coal Equipment Company, Chicago." *Iron Age*, February, 1, 1917.

Kosmann, B. . . . "Die Neueren Kohlenstaubfeuerungs-Apparate." *Stahl und Eisen*, Vol. 15, 1895, pp. 235–42.

" " . . . . "Die Kohlenstaubfeuerung Patent Friedeberg." *Berg und Hüttenmännische Zeitung*, Vol. 53, 1894, pp. 371–74.

Kuzell, C. R. . . . "Coal-Dust Firing in Reverberatory Furnaces." *Engineering and Mining Journal*, February 12, 1916.

Laist, Frederick . . . "Changes in Smelting Practice of Anaconda Copper Mining Company." *Engineering and Mining Journal*, October 7, 1916.

Lavalley, M. . . "Four Crampton." Société des Ingenieurs Civils de France, *Memoires*, 1875. Pp. 266–72; discussion, pp. 272–78.

Leese, John S. . . . "Firing Soft Coal Screenings." *Mechanical World*, Vol. 51, 1912, pp. 160–91.

Lestang, G. . . . "Appareil Friedeberg pour Brûler la Poussière de Charbon." *Revue Industrielle*, Vol. 25, 1894, pp. 461–62.

Lord, James . . . "Use of Pulverised Coal in Metallurgical Furnaces." *Proceedings of the Engineers' Society of Western Pennsylvania*, October, 1913, pp. 363–72; discussion, pp. 371–417.

Mathewson, E. P. . . "Anaconda Coal Pulveriser Plant." *Mining Journal*, July 10, 1915.

McFarlane, George C. . . "Powdered Coal Firing for Steam Boilers." *Engineering and Mining Journal*, Vol. 81, 1906, pp. 901–2.

McMillan, Walter G. . . "On Some Appliances for the Utilisation of Refuse and Dust Fuel." *Society of Arts Journal*, Vol. 34, 1886, pp. 527–40; discussion, pp. 540–42.

Meade, Richard K. . . "Use of Pulverised Fuel for Heating Metallurgical Furnaces." American Institute of Chemical Engineers, Vol. 1, 1908, pp. 98–115.

Moriz, Caspaar . . . "Die Verwendung der Kleinkohle." *Zeitschrift für Berg und Hüttenwesen*, Vol. 45, 1897, pp 373, 401.

Muhlfeld, John E. . . "Pulverised Fuel for Locomotives." *Journal of the American Society of Mechanical Engineers*, December, 1916.

Nakaya, S., and Blakeslee, J. R. . . . . . "The Fushun Colliery and Power Plant of the South Manchuria Railway." *General Electric Review*, September, 1917.

Neumann, Victor von . . "Coal Dust Firing in the Iron Industry." *American Manufacturer and Iron World*, August 28, 1896, p. 300. Abstract from article in *Zeit. Oesterr. Ingen. u. Architekten Verein*, Vol. 48, 1896, pp. 342, 353.

Paton, J. Durmmond . . "Small Coal and Dust: Its Production, Prevention, Treatment and Utilisation, with Special Reference to Dry Mines." *Institution of Mining Engineers, Trans.*, Vol. 45, 1912–1913, pt. 3, pp. 421–46; discussion, pp. 446–49; *Manchester Geological and Mining Society, Trans.*, Vol. 33, pt. 6, pp. 198–223; discussion, pp. 223–60.

Peutsch, Albert . . . "Gas and Coal Dust Firing: A Critical Review of the various Appliances Patented in Germany for this purpose since 1885." Translated by Charles Salter, London, 1901.

Porter, W. E. . . . "Burning of Powdered Coal." *Industrial World*, February 3, 1913.

Pritchard, P. M. . . . "Schwartzkopff System of Coal Dust Firing." *Liverpool Engineering Society, Trans.*, Vol. 28, 1907.

Quigley, W. S. . . . "Powdered Coal as Fuel." *Railway and Engineering Review*, November 15, 1913, pp. 1067–68.

Raymond, A. W. . . . "Pulverised Coal as a Fuel." *Metallurgical and Chemical Engineering*, February 1913, pp. 108–9.

Schmidt . . . . "Kohlenstaubfeuerungen auf der Berliner Gewerbe-Ausstellung." *Gesundheits-Ingenieur*, Vol. 19, 1896, p. 354.

Schneider, C. . . . "Coal Dust Fuel." *Proceedings of Institution of Civil Engineers*, Vol. 123, 1895–96, pp. 516–18. Abstract of Paper in *Mittheilungen aus der Praxis des Dampfkessel und Dampfmaschinen Betriebes*, 1895, p. 336.

" " . . . . "Nachteile der Kohlenstaubfeuerungen." *Alkohol*, Vol. 6, 1896, p. 117.

" " . . . . "Die Kohlenstaubfeuerung." *Zeit. des Verbandes der Dampfkessel Ueberwachungs-Vereins*, Vol. 18, 1895, p. 336.

" " . . . . "Die Schwartzkopff'sche Kohlenstaubfeuerung." *Zeit. des Verbandes der Dampfkessel Ueberwachungs-Vereins*, Vol. 18, 1895, p. 403.

" " . . . . "Versuchergebnisse der De Cammpschen Kohlenstaubfeuerungen." *Mittheilungen aus der Praxis des Dampfkessel und Dampfmaschinenbetriebes*, Vol. 20, 1897, p. 380.

Schrey . . . . "Kohlenstaubfeuerungen." *Glaser's Annalen für Gewerbe und Bauwesen*, Vol. 36, 1895, pp. 213–19; discussion, pp. 219–20. Paper read before the Verein deutscher Maschinen Ingenieure.

Schutze . . . . "Fortschritte auf dem Gebiet der Kohlenstaubfeuerung." *Dampf*, Vol. 13, 1896, p. 1205.

" . . . . . "Kohlenstaubfeuerungs-Apparat." *Uhlands Technische Rundschau*, 1896, No. 3, p. 55.

Severin, S. . . . . "Coal-Dust Firing of Reverberatory Matte Furnaces." *Engineering and Mining Journal*, Vol. 81, 1906, pp. 274–76.

Shelby, Charles F. . . "Coal Dust Firing for Reverberatory Furnaces." *Engineering and Mining Journal*, Vol. 85, 1908, pp. 541–44.

Soper, Ellis . . . "The Rotary Kiln." *American Society of Mechanical Engineers, Journal*, October, 1910; discussion, April, 1911.

" " . . . . "Economy of the Long Kiln." *American Society of Mechanical Engineers, Trans.*, Vol. 29, 1907, pp. 143–48.

Sweeney, J. M. . . . "Use of Pulverised Coal for Fuel under Steam Boilers." *Western Society of Engineers' Journal*, Vol. 9, 1904, pp. 141–49; discussion, pp. 149–160.

Thomas, Edward G. . . "Coal Dust Firing of Reverberatory Furnaces." *Engineering and Mining Journal*, Vol. 85, 1908, pp. 269–70.

Thurston, R. H. . . . "A Manual of Steam Boilers, their Design, Construction and Operation." New York, Wiley, 1888, pp. 164–65.

Trantschold, Reginald . . "Burning Pulverised Coal at the Mine." *Coal Age*, July 15, 1916.

Travis, H. J. . . . "Burning Powdered Coal." *Power*, Vol. 24, 1904, pp. 168–96, 271.

" " . . . . "Powdered Coal and Steel Annealing." *American Machinist*, Vol. 27, pt. 1, 1904, pp. 791–92.

Turin, André . . . "Les Foyers de Chaudières." Paris, Dunod and Pinat, 1913, pp. 156–61.

U.S. Steam Engineering Bureau (Navy Dept.) "Annual Report, Washington Government," 1876.

Vacquiers . . . . "Chauffage au Pulvérin de Charbon." *La Vie Scientifique*, 1897, pt. 1, pp. 253–54.

Wakeman, W. H. . . "Burning Low-Priced Fuel." *American Machinist*, Vol. 22, 1899, p. 101.

Warlich . . . . "Kohlenstaubfeuerung und Vermahlung der Kohle." *Dampf*, Vol. 41, 1897, pt. 1, pp. 49–51.

Whigham, William . . "Fuel Possibilities in Steel Making." *Iron Age*, November 6, 1913, pp. 1056–59.

Wilson, E. B. . . . "Firing with Coal Dust." *Colliery Engineer*, October, 1915.

" " . . . . "Powdered Coal Preparation and Firing in Germany." *Journal of American Society of Mechanical Engineers*, November, 1915.

Wegener . . . . "Baensch-Feuerungen zur Verfeuerung von Teer, Kohlenstaub, etc." *Asphaltkunde u. Teer Industrie Zeitung*, Vol. 6, 1906, p. 4.

Wood, W. D. . . . "Powdered Fuel and Explosions" *Railway Age Gazette*, July 18, 1913. Letter, pp. 83–84.

" " . . . . "Powdered Fuel for Locomotives." *Railway Age Gazette*, July 4, 1913, pp. 13–15; August 1, p. 174.

Worth, W. S. . . . "Firing Boilers with Pulverised Coal." *Power*, Vol. 33, 1911, pp. 264–67.

Wright, C. H. . . . "Pulverised Fuel for Boiler Firing." *Electrical World*, March 15, 1913, pp. 567–69.

Zarniko and Propfe . . "Firing with Coal Dust and Coal Grinding Processes." *Proceedings of Institution of Civil Engineers*, Vol. 126, 1895–96, pp. 473–74. Abstract of article in *Gesundheits-Ingenieur*, 1896, p. 210.

BULLETINS AND TECHNICAL PAPERS ON FUEL SUBJECTS ISSUED BY THE DEPARTMENT OF MINES, WASHINGTON, U.S.A.

Combustion and Fuel Firing.

Reference.	Title.	Author.
Technical Paper 63.	"Factors Governing the Combustion of Coal in Boiler Furnaces."	J. K. Clement, I. C. W. Frazer, and C. E. Augustine.
T.P. 205.	"Saving Coal in Boiler Plants."	H. Kreisinger.
Bulletin 39.	"The Smoke Problem at Boiler Plants."	D. T. Randall.
T.P. 195.	"The Tars Distilled from Bituminous Coal in Hand-Fired Furnaces."	S. H. Katz.
T.P. 80.	"Hand Firing Soft Coal under Power Plant Boilers."	H. Kreisinger.
T.P. 219.	"Combustion and Flue Gas Analysis."	U.S. Fuel Administration.
Bulletin 35.	"The Utilisation of Fuel in Locomotive Practice."	W. F. M. Goss.
T.P. 43.	"The Influence of Inert Gas on Inflammable Gascous Mixtures."	T. K. Clement.
T.P. 137.	"Combustion in the Fuel Bed of Hand-Fired Furnaces."	H. Kreisinger and C. E. Augustine.
T.P. 139.	"Low Rate Combustion in Fuel Beds of Hand-Fired Furnaces."	H. Kreisinger, C. E. Augustine, and S. H. Katz.
T.P. 207.	"Combustion Experiments with North Dakota Lignite."	H. Kreisinger, C. E. Augustine, and W. C. Harper.
Bulletin 135.	"Combustion of Coal and Design of Furnace."	H. Kreisinger, C. E. Augustine, and F. K. Ovitz.
Bulletin 40.	"The Smokeless Combustion of Coal in Boiler Furnaces."	D. T. Randall and H. W. Weeks.

Fuel : Its Composition and Storage.

T.P. 16.	"Deterioration and Spontaneous Heating of Coal in Storage."	H. C. Porter and F. K. Ovitz.
Bulletin 1.	"The Volatile Matter of Coal."	H. C. Porter and F. K. Ovitz.
T.P. 113.	"Some Properties of Water in Coal."	H. C. Porter and O. C. Ralston.
Bulletin 129.	"The Fusibility of Coal Ash and the Determination of the Softening Temperature."	A. C. Fieldner, A. C. Hall, and A. L. Field.
Bulletin 97.	"Sampling and Analysing Flue Gases."	H. Kreisinger and F. K. Ovitz.
T.P. 235.	"Safe Storage of Coal."	H. H. Stock.
T.P. 170.	"The Diffusion of Oxygen through Stored Coal."	S. H. Katz.
T.P. 123.	"Notes on the Use of Low-Grade Fuel in Europe."	R. H. Fernald.
T.P. 55.	"The Production and Use of Brown Coal in the Vicinity of Cologne, Germany."	C. A. Davis.
Bulletin 2.	"North Dakota Lignite as a Fuel for Power-House Boilers."	D. T. Randall and H. Kreisinger.
Bulletin 89.	"Economic Methods of Utilising Western Lignites."	E. J. Babcock.
Bulletin 20.	"The Explosibility of Coal Dust."	G. S. Rice, J. C. W. Frazer, Axel Larsen, F. Haas, and Carl Scholz.

Fuel: Its Composition and Storage.

Reference.	Title.	Author.
Bulletin 16.	"The Uses of Peat."	C. A. Davis.
T.P. 279.	"Economic Combustion of Waste Fuels."	D. Moffat Myers.
Bulletin 209.	"Fusibility of Ash from Coals of the United States."	W. A. Selvig and A. C. Fieldner.

Distillation and Fuel Products.

Reference.	Title.	Author.
T.P. 89.	"Coal Tar Products."	H. C. Porter.
T.P. 242.	"Why and How Coke should be used for Domestic Heating."	H. Kreisinger and A. C. Fieldner.
Bulletin 33.	"Run-of-Mine and Briquetted Coal on the Torpedo Boat *Biddle*."	W. H. Ray and H. Kreisinger.
T.P. 140.	"The Primary Volatile Products of the Carbonisation of Coal."	G. B. Taylor and H. C. Porter.
Bulletin 24.	"Binders for Coal Briquettes."	J. E. Mills.
Bulletin 58.	"Fuel-Briquetting Investigations."	C. A. Wright.

Heat Transference and Testing.

Reference.	Title.	Author.
Bulletin 8.	"The Flow of Heat through Furnace Walls."	W. T. Ray and H. Kreisinger.
T.P. 240.	"Boiler and Furnace Testing."	R. T. Strohm.
Bulletin 145.	"Measuring the Temperature of Gas in Boiler Settings."	H. Kreisinger and J. E. Barkley.

Coal Gas.

Reference.	Title.	Author.
Bulletin 55.	"The Commercial Trend of the Producer Gas Power Plant."	R. H. Fernald.

INDEX

Typical Arrangement of 'Screen Mill' Plant.

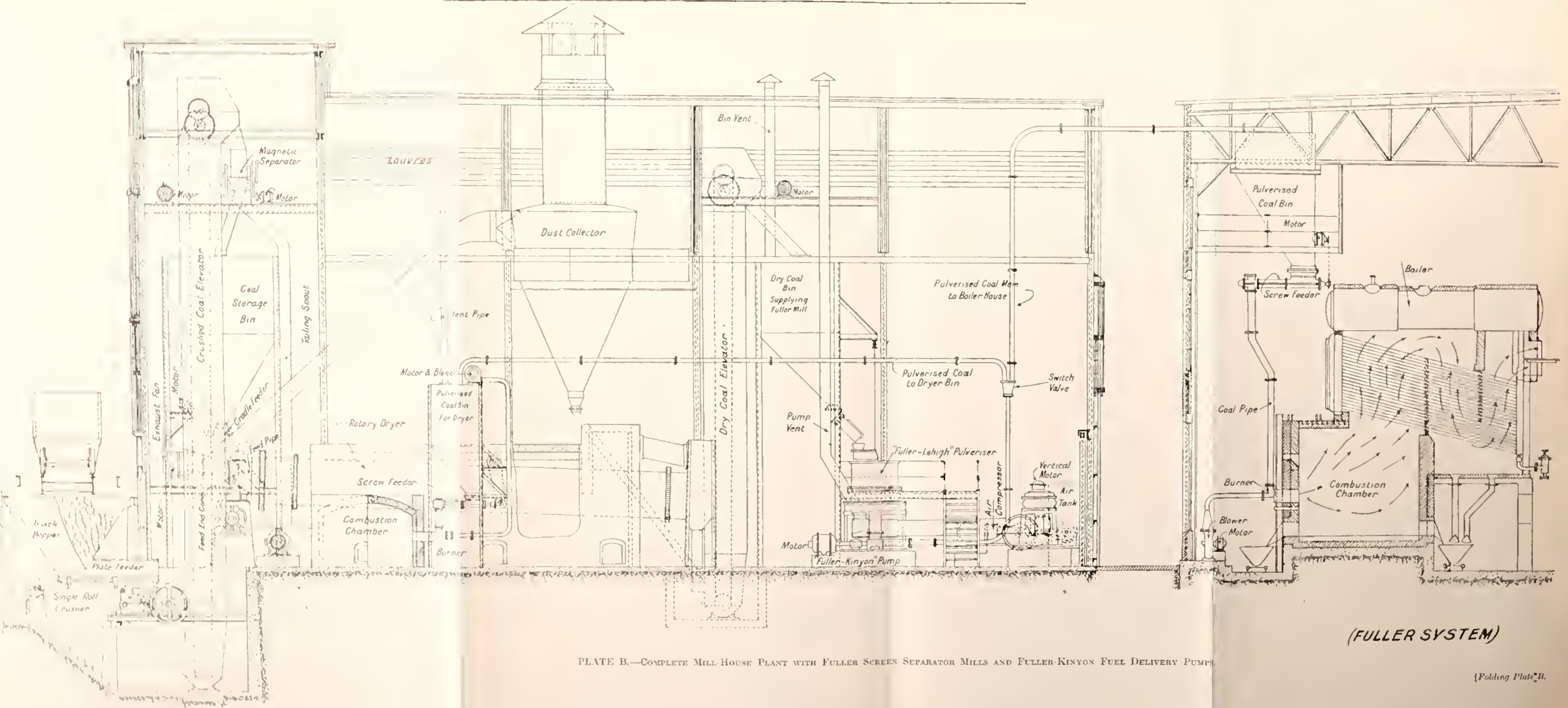


PLATE B.—Complete Mill-House Plant with Fuller Screen Separator Mills and Fuller-Kinyon Fuel Delivery Pumps.

[Folding Plate B.

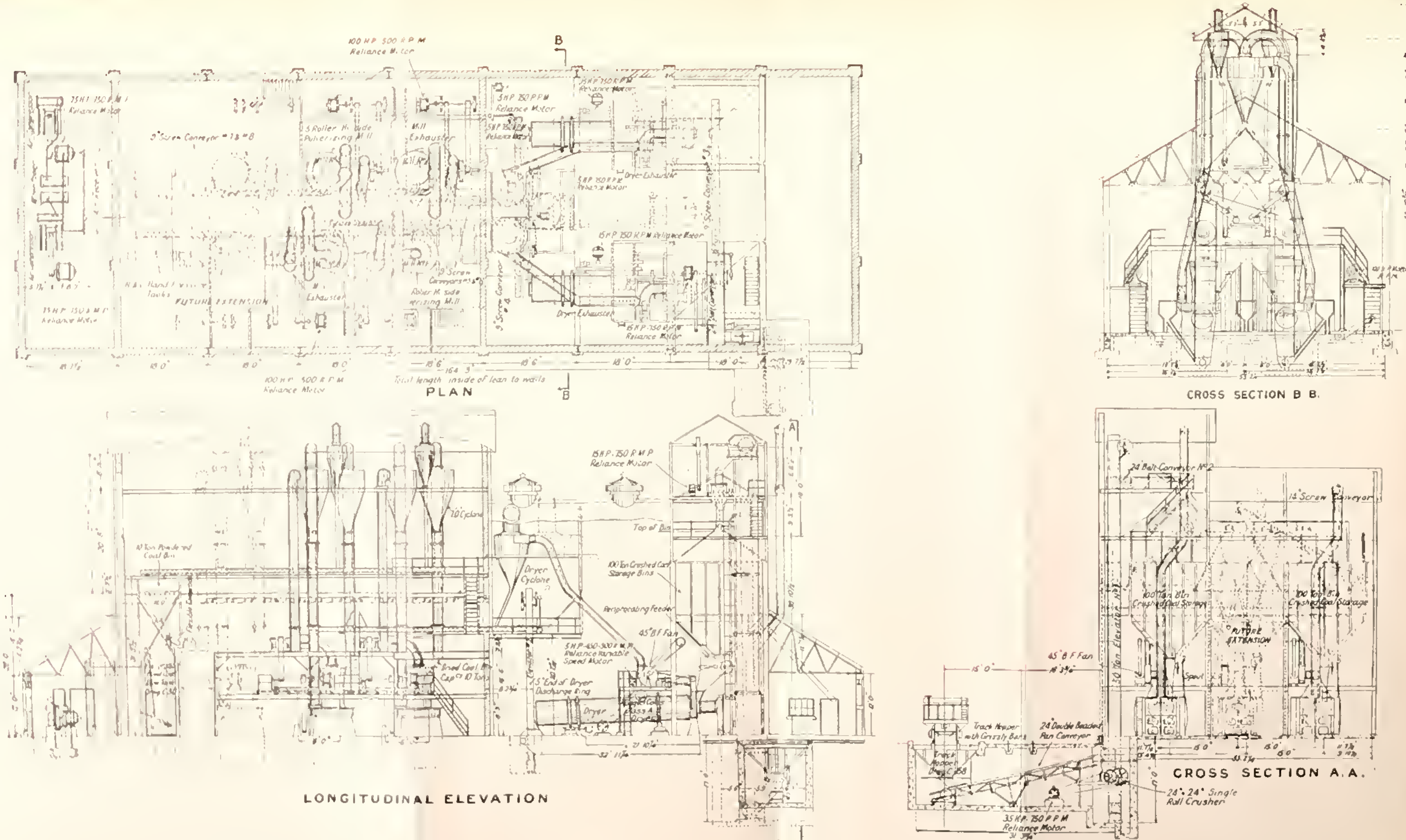


PLATE C. Complete Mill House Plant with Air Separator, Raymond Mills and Quigley "Blowing Tank" Fuel Delivery.

[Folding Plate C.

(QUIGLEY SYSTEM.)